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00-RF-01823

Report on Soil Erosion and Surface Water Sediment Transport Modeling for the Actinide Migration Evaluation at the Rocky Flats Environmental Technology Site

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Rocky Flats Environmental Technology Site

August 2000

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Rocky Flats Environmental Technology Site

August 10, 2000

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REPORT ON SOIL EROSION AND SURFACE WATER SEDIMENT TRANSPORT MODELING FOR THE ACTINIDE MIGRATION EVALUATION AT THE ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE – CSD-004-00

Dear Community Member:

Enclosed please find the "Report on Soil Erosion and Surface Water Sediment Transport Modeling for the Actinide Migration Evaluation at the Rocky Flats Environmental Technology Site", dated August 2000. This report represents the culmination of two years of effort developing, calibrating, and receiving peer review on the Rocky Flats Environmental Technology Site Watershed Erosion and Sediment Transport Modeling effort. This modeling effort was undertaken to develop a management tool to evaluate erosional impacts from storm events based on current Site conditions, potential remedial actions, and regulatory closure. We are planning a stakeholder workshop to discuss the report; the time of that meeting will be forwarded to you under separate cover.

We welcome your comments. Please forward all comments on the report to us in writing by the close-of-business on September 22, 2000. We will respond in writing to comments received by then. Comments that can be reasonably incorporated into next fiscal year's model refinement and future scenario work will be incorporated. On the other hand, comments, which are beyond next fiscal year's scope, will be considered for future work. Please feel free to contact Russell at 303-966-9692 or Chris at 303-966-9887.

Sincerely,

Russell McCallister
Environment and Infrastructure
Rocky Flats Field Office
Department of Energy

Christine S. Dayton
Environmental Systems & Stewardship
Kaiser-Hill Company, L.L.C.

CSD/JCM

Attachments: as stated

cc:
Steve Gunderson, CDPHE
Tim Rehder, EPA

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00-RF01823

Report on Soil Erosion and Surface Water Sediment Transport Modeling for the Actinide Migration Evaluations at the Rocky Flats Environmental Technology Site

August 2000

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Acknowledgments

The work presented in this report has been peer reviewed by the Actinide Migration Evaluation (AME) advisors, a team of leading experts in actinide chemistry, fate and transport, and erosion/sediment transport. The lead AME peer reviewer for the erosion and sediment transport modeling effort is Dr. Leonard J. Lane, nationally recognized hydrologist, from Tucson, Arizona. Dr. Lane provided consultation on model calibration procedures, model performance, and interpretation of results. Dr. Lane also provided technical peer review for this report. The AME modeling team appreciates all effort the AME advisors put into this document.

The AME modeling group also appreciates the generosity of the Colorado State University (CSU)/ U.S. Department of Energy Environmental Management Science Program (EMSP) rainfall simulation study group in providing the opportunity to observe their simulations performed near the Site and in sharing their data for use in calibration of the Site's erosion-runoff model.

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LIST OF ACRONYMS

ac	acres
af	acre-feet
Am-241	americium-241
AME	Actinide Migration Evaluation
ARS	Agricultural Research Service
basi	interrill basal cover
basr	rill basal cover
BLUE	best least-squares unbiased estimator
°C	DEGREES CENTIGRADE
cancov	CANOPY COVER
CDPHE	Colorado Department of Public Health and the Environment
CEC	CATION EXCHANGE CAPACITY
cfs	cubic feet per second
CLIGEN	Climate generator component of WEPP
cm	centimeters
COE	U.S. Army Corp of Engineers
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
CSM	Colorado School of Mines
CSU	Colorado State University
CUHP	Colorado Urban Hydrograph Procedure
CV	coefficient of variation
CWQCC	Colorado Water Quality Control Commission
D&D	decontamination and decommissioning
DOE	Department of Energy
DQO	data quality objective
EMSP	U.S. Department of Energy Environmental Management Science Program
ft	foot/feet
ft^2	foot/feet squared
FY	fiscal year

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LIST OF ACRONYMS
(Continued)

g	grams
g/cm^3	grams per centimeter cubed
GIS	Geographic Information System
GSTARS	Generalized Stream Tube Model for Alluvial River Simulation
HEC-6	Hydrologic Efficiency Code 6
HEC-6T	Sedimentation in Stream Networks Model
HPGe	high purity geranium detector
IA	Industrial Area
IM/IRA	interim measure/interim remedial action
in	inches
km	kilometers
km^2	square kilometers
kg	kilograms
kg/ha	kilograms per hectare
kg/m^2	kilograms per square meter
L	liter
L/s	liters per second
lb	pounds
lb/m^2	pounds per square meter
m	meters
mg/L	milligram per liter
μg(s)	microgram(s)
mi	miles
mi^2	square miles
mm	millimeters
mm/hr	millimeters per hour
MUSLE	Modified Universal Soil Loss Equation
OFE	Overland Flow Element
OM	Organic Matter

LIST OF ACRONYMS
(Continued)

OU	operable unit
pCi/ft^2	picocuries per square foot
pCi/g	picocuries per gram
pCi/L	picocuries per liter
pCi/m^2	picocuries per square meter
plive	maximum live standing biomass
POC	Point of Compliance
POE	Point of Evaluation
Pu-239/240	plutonium-239,240
resi	interrill litter surface cover
resr	rill litter surface cover
RFCA	Rocky Flats Cleanup Agreement
RFETS	Rocky Flats Environmental Technology Site
RFI	RCRA Facility Investigation
RMRS	Rocky Mountain Remediation Services
Rocky Flats	Rocky Flats Environmental Technology Site
roki	interrill rock cover
rokr	rill rock cover
root10	roots in the top 10 cm
rootf	percentage of live and dead roots at the start of the year
rrough	initial random roughness of the soil surface
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Service
SID	South Interceptor Ditch
Site	Rocky Flats Environmental Technology Site
SWRBB	Simulator for Water Resource in Rural Basins
t/ac	tons per acre
T/ha	metric ton per hectare

LIST OF ACRONYMS
(Continued)

TIN	Triangular Irregular Networks
TSS	Total Suspended Solids
U	URANIUM ISOTOPES
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
WEPP	Watershed Erosion Prediction Project
WWE	Wright Water Engineers

Executive Summary

The surface soils over portions of the Rocky Flats Environmental Technology Site (Site) were contaminated by accidental releases of radionuclides (actinides) including plutonium-239,240 (Pu-239/240) and americium-241 (Am-241). The Pu-239/240 and Am-241 are strongly associated with the soil particles and do not dissociate significantly in water. Remediation of the actinide-contaminated soils is planned prior to Site regulatory closure. At that time, the soils must be clean enough so that when they are eroded and transported into streams and ponds, the surface-water Pu-239/240 and Am-241 concentrations will not exceed surface water-quality standards. Understanding the processes and variables that contribute to and control soil erosion is important to achieving a final remedial design that limits erosion, sediment transport, and associated migration of any residual actinide contamination.

The Site's Actinide Migration Evaluation Project (AME) is focused on understanding actinide mobility in the environment. The AME has completed a study to estimate the impacts of soil erosion and sediment transport on Site surface water quality. Two goals of the study are: 1) to develop models that predict concentrations of Pu-239/240 and Am-241 in surface water resulting from a wide range of storm events, and 2) to develop tools to evaluate impacts of potential remedial actions, hydrologic modifications and land uses on surface water quality.

In this evaluation, the AME developed new and adapted existing specialized techniques in erosion, sediment transport, and surface water concentration modeling to investigate soil erosion, sediment transport, and associated Pu-239/240 and Am-241 transport in the South Interceptor Ditch (SID), Woman Creek, and Walnut Creek watersheds. The AME also developed and tested erosion and surface soil contaminant mobility mapping techniques. Calibration of the models using Site monitoring data demonstrated that the models provide reasonable tools for management decision-making, remedial design and evaluation, and final regulatory closure planning.

A comprehensive geostatistical analysis of the spatial distribution of actinide contamination in Site soils has been developed in conjunction with this study using kriging, a geostatistical method for spatial contouring of soil concentration data. The kriged Pu-239/240 and Am-241 distributions and the erosion and sediment transport models have been linked to create the following:

- Soil mobility maps;
- Actinide mobility maps;

- Estimated surface water actinide concentrations and probabilities for their occurrence; and
- A tool with the potential to guide remediation and environmental management decisions at this Site and others.

The predicted spatial distributions of soil erosion and Pu-239/240 and Am-241 movement were derived from Geographic Information System (GIS) interpretations of the erosion modeling results, combined with the kriging analysis of the Pu-239/240 and Am-241 contamination in the surface soil. The data on contaminant and erosion distributions were mapped separately, and the information was joined to create actinide mobility maps . The mobility maps show areas where the Site will benefit most from soil remediation and erosion/sedimentation control actions.

A soil actinide concentration adjustment model was created to determine the soil contamination that could remain in the Site soils and still be protective of surface water quality. Results of this model are currently only available for the SID watershed. The adjustment model has not been extended to the other watersheds, but could be utilized as a tool in the future when developing the Site's final remedial design. Remediation of the very low levels of actinide soil contamination in the Woman Creek and Walnut Creek watersheds was not addressed in this study.

The following conclusions are derived from the analysis presented in this report:

1. The 100-year annual average erosion rate for the Site watersheds is estimated to vary from 0.384 metric tons per hectare (T/ha) (0.171 tons/acre [t/ac]) in the SID drainage to 0.221 T/ha (0.099 t/ac) in the Woman creek drainage, resulting from about 4 to 6 percent of the annual precipitation leaving the Site as runoff. The erosion rate translates into an estimated annual erosion depth of 0.025 to 0.046 millimeters (mm) (0.001 to 0.002 inches [in]) when averaged across the Site. This is an average for the Site, the annual erosion depth is much greater in some area.

2. The great majority of the predicted erosion is due to large, infrequent storms and the average values do not convey the very large variation in annual values of runoff and erosion due to variation in precipitation from year to year. The annual erosion estimates for the SID watershed vary from a minimum of 0.01 T/ha (0.004 t/ac) to a maximum of 3.54 T/ha (1.58 t/ac) for the 100-year simulation. Soil losses more than double the average can be expected about 16 years out of 100 years or about once every 6 or 7 years. The 100-year average is very similar to the events with a 10- to 12-year return interval.

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3. Actinide source areas that have the potential to impact surface water quality due to erosion and sediment transport are the following:
   - The 903 Pad and Lip Area (903 Pad Area);
   - An area south and southwest of the old firing range and access road to the north of the SID;
   - The Woman Creek watershed between Pond C-1 and the Mower Diversion; and
   - The areas near the A- and B-series Ponds, South Walnut Creek, and the north-facing hillslopes adjacent to South Walnut and Walnut Creeks.
4. Uncertainties associated with the erosion and sediment modeling results and their incorporated assumptions have been identified, qualified, and quantified where possible. The estimates contained in this report are considered to be accurate to within an order of magnitude. Comparisons of model simulation results to measured data provide examples where erosion and sediment transport appear to be slightly underestimated and other examples where erosion and sediment transport appear to be overestimated by as much as a factor five.
5. Simulated Pu-239/240 and Am-241 concentrations in Site streams identify areas where soil contamination levels are likely to impact surface water quality. These areas are the following:
   - The SID watershed from the 903 Pad Area east to Pond C-2;
   - The Woman Creek watershed from Antelope Springs to the Mower Ditch and from the Smart Ditch Overflow to Indiana Street;
   - The Mower Ditch;
   - North and South Walnut Creeks and the A- and B-Series ponds from the Industrial Area (IA) to the confluence with No Name Gulch; and
   - No Name Gulch from the Landfill Pond Dam to about 275 meters (m) (300 yards) upstream from the confluence with Walnut Creek.
6. The model simulations for the 10- and 100-year events, coupled with the soil actinide concentration adjustment model results for the SID, indicate that remediation of contaminated soil in the 903 Pad Area to actinide levels lower than those currently under consideration will still potentially result in surface water actinide concentrations above 0.15

pCi/L in at least some portion of the SID. The Action Level Framework (ALF) "Point of Evaluation" action level of 0.15 pCi/L for Pu-239/240 and Am-241 is recognized as a goal in the Rocky Flats Cleanup Agreement (RFCA) (U. S. Department of Energy [DOE], 1996a). The combination of the SID and Pond C-2 are currently effective in controlling levels of actinides originating from the 903 Pad area in surface water leaving the Site. The selection of a final remedial design for the SID drainage based on a final surface water standard will depend on the completion of several steps in the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) process. Based on the results presented in this report, it is recommended that the Site evaluate a combination of remediation, erosion controls, hydrologic controls, and management controls to protect surface water quality.

The models developed for this report are tools for making informed decisions regarding remedial actions for actinide contaminated soils at the Site. The tools will be used to evaluate combinations of soil remediation, erosion controls, hydrologic modifications, land uses, and other management alternatives to assess their impacts on mitigating the movement of Pu-239/240 and Am-241 via the soil erosion and sediment transport pathway. The modeling process developed by the AME modeling group can also be applied to soil contamination problems at other sites where contaminants are insoluble and have a strong affinity for sorption or binding to the solid phase (e.g., soil and sediment). Conclusions derived from this modeling effort should be characterized as preliminary until the modeling work planned for fiscal year 2001 (FY01) and other related investigations, such as the Site-wide Water Balance, have been completed.

Modeling of future scenarios for soil remediation, hydrologic modifications, extreme natural disasters (floods, fires, etc.), and the final Site land configuration design study is planned for FY01. The future scenario models will provide additional tools to facilitate development of a final remedial design.

1.0 Introduction

1.1 Purpose

This report presents results of the Actinide Migration Evaluation (AME) Soil Erosion and Surface Water Sediment Transport Modeling Project activities. The goal of the AME Modeling Project is to estimate and quantify actinide loading rates to surface water, in the short- and long-term, under the range of climatological and environmental conditions that may occur at the Site. The transport of soil by erosion and overland flow is modeled using the Watershed Erosion Prediction Project (WEPP) model (Flanagan and Livingston, 1995). The transport of sediments by surface water within Site drainage channels is estimated with the Sedimentation in Stream Networks (HEC-6T) model (Thomas, 1999).

The AME is investigating the mobility of plutonium-239/240 (Pu-239/240), americium-241 (Am-241), and uranium-234, 235, 238 (U) isotopes in the Site environment. The goal of the AME is to achieve the objectives contained in the AME Data Quality Objectives (DQO) document (Kaiser-Hill, 2000b).

These objectives are addressed by performing mathematical modeling of the actinide transport processes (identified as important contributors) in the Site environment. Current information suggests that actinide transport in sediments by overland flow (soil erosion) and in channeled surface water is an important transport mechanism that can impact surface-water quality in both the short- and long-term. The most efficient method for assessing contributions of soils and sediments to surface water loads of actinides is through the use of models. The current work is limited to consideration of transport in and by water.

Mathematical models were calibrated with measured data and then used to make predictions about potential future conditions. Extensive discussion of the calibration procedures and results are presented in Appendices A and C. After the calibration step, the model output data were compared to Site monitoring data to assess model performance. When reasonable modeling results were finally obtained and model calibration was confirmed, the results were used to draw conclusions about how soil erosion and sediment transport could affect Site water quality for current conditions.

1.2 Regulatory Framework

Surface water standards and action levels are established in the Rocky Flats Cleanup Agreement (DOE, 1996a). Surface water monitoring at the Site is performed in accordance in the Integrated Monitoring Plan (IMP) (Kaiser-Hill, 1999) and the Industrial Area Interim Measures/ Interim Remedial Action Decision Document (IA IM/IRA) (EG&G, 1994).

RFCA provides an Action Level Framework (ALF) for Point of Evaluation (POE) monitoring and specific standards for Point of Compliance (POC) monitoring. POE monitoring is performed within Segment 5, which includes the terminal ponds, the main stream channels of North and South Walnut Creek, Pond C-2, and the SID (Figure 1). POC monitoring is performed within Segment 4, which includes Walnut and Woman Creeks below the terminal ponds (Figure 1). All sampling at POEs and POCs is continuous, flow-paced composite sampling.

Evaluation of radionuclide activity data collected from POE and POC monitoring locations is currently performed using 30-day volume-weighted moving averaging. The 30-day average for a particular day at a given location is calculated using a 'window' of time which extends back over the previous 30 days for which both flow and measurement of activity occurred. These 30-day averages are compared to appropriate Action Levels and Standards and reported according to the requirements of the IMP and RFCA.

1.3 Scope

The Conceptual Model for the AME at the Rocky Flats Environmental Technology Site (RFETS or Site) (Kaiser-Hill Company, L.L.C. [Kaiser-Hill], 1998a) discusses potential pathways for actinide migration in the environment and their relative importance based on current information. The physical transport of Pu-239/240 and Am-241 by the processes of erosion, overland flow, and channel flow is a dominant migration pathway. Research supported by the AME has shown that Pu-239/240 and Am-241 are predominantly transported in surface water on suspended solids (Santschi et al., 1999).

The WEPP model was used to estimate the runoff and sediment yields from Site hillslopes and to estimate runoff and sediment loading to channels within the South Interceptor Ditch (SID), Walnut Creek, and Woman Creek watersheds. The WEPP sediment and runoff output were then input to the HEC-6T model to estimate stream flow and sediment transport.

The combined output of the WEPP and HEC-6T models was used to identify surface water concentrations, sources, and sinks for Pu-239/240 and Am-241 in the watersheds. Techniques were developed to estimate the quantities of Pu-239/240 and Am-241 associated with the sediment in the watersheds using the spatial distribution of Pu-239/240 and Am-241 concentrations in the soil and data quantifying the relationship between concentration and the particle size distribution of water-stable aggregates in the soil (Rocky Mountain Remediation Services [RMRS], 1998a). The estimated activity of the erosion sediments were combined with the results of the sediment transport modeling and used to model: 1) effects of the present Site configuration and soil contaminant levels on surface water quality; and 2) effects of reduced soil actinide levels on surface water quality. Future Site configurations are planned to be modeled in fiscal year 2001 (FY01).

This report provides information and tools needed to determine actinide levels and management practices for Pu-239/240 and Am-241 in Site soils that will be protective of surface water quality in both the short- and long-term. The models created for this report can be used as planning tools for remediation of surface soils, long-term protection of surface water, watershed management, final Site configuration, and preparation of the risk assessment needed for Site regulatory closure.

This report includes the following (add some detail to this section?):

- Descriptions of the three drainages that were modeled: Woman Creek, the SID, and Walnut Creek (Section 2);
- The conceptual model for surface transport of actinides and a description of soil erosion and sediment transport processes (Section 3);
- A discussion of the selection of the models and model components (Section 4);
- A description of the Site models and model data needs (Section 5);
- Descriptions of the steps taken to integrate the models and the modeling DQOs (Section 6);
- Results of hillslope erosion modeling, including predicted rates of movement for Pu-239/240 and Am-241 in surface soils (Section 7);
- Results of channel sediment transport modeling (Section 8);
- The results of the Pu-239/240 and Am-241 surface water transport modeling, including the effects of various soil cleanup levels on surface water concentrations of Pu-239/240 and Am-241 (Section 9);
- A description of modeling uncertainties (Section 10, supplemented in Appendix D);
- A project summary and description of future planned work (Section 11);
- References (Section 12);
- Erosion and actinide mobility maps (Figures at end of report);

- A detailed description of the erosion model Site-specific input parameters, calibration procedures, and comparisons of model predictions with measured surface water data (Appendix A);
- The Kriging analysis used in the Pu-239/240 and Am-241 transport estimates (Appendix B);
- A description of the models built to track Pu-239/240 and Am-241 in sediments, from hillslope to deposition or drainage outlet (Appendix B);
- A detailed description of the sediment transport model calibration process and a comparison of the results to measured surface water data (Appendix C);
- An uncertainty analysis of the modeling project (Appendix D); and
- A CD-ROM with model input and output data and other Site data (Appendix E).

1.4 Uncertainties

Natural physical systems are typically highly complex and often contain components that are not completely understood or measurable. Any model of a natural system must make simplifying assumptions to reduce the level of complexity, account for knowledge gaps, and to offer a solution that is feasible given available technology and resources.

Computer models used for this project rely on underlying conceptual models of physical processes, mathematical algorithms that attempt to replicate these processes, and measurements or input data for the models. Uncertainty associated with modeling results can be attributed to three general sources: 1) structural uncertainty; 2) input uncertainty; and 3) parameter uncertainty.

Structural uncertainty relates to the degree to which the models accurately and completely represent the physical system being analyzed. Input uncertainty reflects the spatial and temporal variability of the input data along with measurement errors. Parameter uncertainty refers to the uncertainty associated with internal model parameters, which are fixed and not usually adjusted or available for adjustment by the user. These three categories of uncertainty, as they pertain specifically to this erosion, sediment, and actinide transport modeling project, are discussed in detail in Appendix D.

1.5 Future Scope and Refinements

During the remainder of FY00 and through FY01, additional erosion, sediment, and actinide transport modeling is planned for a range of environmental conditions. These include various land surface configurations, hydrologic modifications, remediation scenarios, and extreme events, such as range fires (Kaiser-Hill, 1999). Results from these modeling scenarios will provide additional information to assist with management decisions leading to Site regulatory closure.

In addition, if time and resources allow further study, related subjects warranting further investigation include (listed in relative order of priority):

- Including bed erosion in the sediment transport model to assess the impacts on actinide transport;
- Modeling a wider range of storm event frequencies to provide a better understanding of the relationship between precipitation and actinide concentrations in surface water; and
- Running the erosion and sediment transport models with the detention ponds at varying levels to determine impacts on surface water during different scenarios of pond operations.

2.0 Study Area and Climate

Three drainage basins collect surface water at the Site (Figure 1). The basins are drained by natural, intermittent to ephemeral, and perennial streams that generally flow from west to east. The northwest portion of the Site is drained by Rock Creek, which flows into Coal Creek east of the Site. This drainage is not considered in the study, since it has not been affected by Site activities. Walnut Creek drains the northeast quadrant of the Site. The SID runs west to east between the south edge of the Industrial Area (IA) and Woman Creek and collects runoff from the IA and the Buffer Zone, including the 903 Pad Area. Woman Creek collects water from west of the Site and from the southern portion of the Site. The drainage area of both watersheds, which are described below, are included in the soil erosion and surface water sediment transport modeling.

2.1 Woman Creek

The on-Site portion of the Woman Creek watershed is approximately 8 square kilometers (km^2) (3.1 square miles [mi^2]). Woman Creek is formed by two branches to the west, known as North Woman Creek and South Woman Creek. These branches converge about 1,800 feet east of the western Site boundary (Figure 1). The flow in Woman Creek is intermittent. There are two detention ponds in the Woman Creek drainage: 1) Pond C-1, which is located within the stream channel and is currently configured for continuous flow-through operation; and 2) Pond C-2, which is off-channel and used to collect runoff from the south side of the IA, the 881 Hillside, and the 903 Pad Area via the SID. Pond C-2 is batch discharged, typically once a year, to Woman Creek. In the past, the majority of water from Woman Creek was diverted into Mower Ditch. The diversion was shut off in 1997, and now water flows off Site in the natural Woman Creek channel to the Woman Creek Reservoir on the east side of Indiana Street.

Antelope Springs Gulch is a perennial feature that carries water from Antelope Springs, a large seep to the south of Woman Creek. It normally has base flow throughout the year. Antelope Springs Gulch flows into Woman Creek just upstream of Pond C-1.

The SID was constructed in 1980 to divert surface water runoff from the southern portion of the IA to Pond C-2 (Figure 1). It was originally designed to handle a 100-year precipitation event. Erosion, sedimentation, and encroachment of vegetation have reduced the SID's flow velocity and capacity (EG&G, 1992a). The SID was modeled as a separate drainage, because its flow is entirely contained by Pond C-2.

2.2 Walnut Creek

The Walnut Creek watershed area is approximately 3.7 mi^2 (9.6 square km^2)(Figure 1). The watershed is comprised of two perennial streams: 1) South Walnut Creek and North Walnut Creek; and 2) ephemeral to intermittent features known as No Name Gulch and the McKay Bypass Canal. The Present Landfill and the Landfill Pond are situated in the headwaters of No Name Gulch. The Landfill Pond does not discharge into the gulch. Flows in No Name Gulch result primarily from base flow and runoff from surrounding hillsides.

Water in the upper reaches of North Walnut Creek (northwest of the IA) is diverted to the McKay Bypass, which flows to the north of the Present Landfill. Until 1999, this water reentered the Walnut Creek drainage downstream of No Name Gulch. A diversion structure and pipeline were installed to route water to Great Western Reservoir, precluding flow from Walnut Creek. However, for this study the diversion is assumed to be absent. Water draining from the north side of the IA enters North Walnut Creek and is diverted by pipeline around Ponds A-1 and A-2 into A-3. Ponds A-1 and A-2 are used for spill control for the IA and do not discharge into the drainage. Pond A-3 is batch released to Pond A-4, which is batch discharged into the North Walnut Creek channel.

South Walnut Creek receives runoff from the IA, including the Central Avenue Ditch and a portion of the 903 Pad Area. The natural channel of South Walnut Creek has been greatly changed by construction in the IA during operation of the Site and the B-Series Detention Ponds in 1980 (Figure 1). Ponds B-1 and B-2 are normally off-line but are maintained at a level to keep sediments wet and are reserved for IA spill control. Water in Pond B-3 is batch discharged to B-

4, then flows through to B-5, which is then batch discharged to South Walnut Creek. A gate valve and stand pipe were installed in Pond B-5 in 1998 to allow for direct batch releases.

The soil erosion and surface water transport modeling study includes all areas drained by the Woman Creek (including the SID) and Walnut Creek watersheds. The study area is limited to the Site property, except for a small area of grazed land on the upper reaches of Woman Creek.

2.3 Climate

The Site's climate is semi-arid, with an annual average precipitation of 368 millimeters (mm) (14.5 inches [in]), about 50 percent of which occurs as rain (DOE, 1995a). The monthly distribution of rainfall is shown in Figure 2. Evapotranspiration averages over 400 mm (15.8 inches) per year, creating a water deficit in most years (Wright Water Engineers [WWE], 1995). Much of the runoff feeding the Site drainages occurs rapidly, originating from the mainly impervious IA surfaces (RMRS, 1998b). Buffer Zone runoff from small to intermediate events occurs chiefly on roads, steep hillslopes, and areas where culverts feed IA runoff to the Buffer Zone. Precipitation events greater than about 12.7 mm (0.5 in) per 24 hours produce runoff in some areas (EG&G, 1993a and 1993b).

3.0 Conceptual Model for Surface Transport of Actinides

As noted in Section 1.2, a Site conceptual model was developed to provide a qualitative understanding of Pu-239/240 and Am-241 sources and transport pathways for the Walnut and Woman Creek watersheds and a framework for quantifying transport rates of actinides for Site environmental conditions (Kaiser-Hill, 1998a). Pu-239/240 and Am-241 are tightly adsorbed to soil particulates, with up to 90 percent retained in the upper 15 centimeters (cm) of the soil profile (Webb et al., 1997; Litaor et al., 1996; Webb, 1992; Choppin, 1992; and Watters et al., 1983). The Pu-239/240 and Am-241 present in the surface soil can be transported with associated particulates by overland flow to surface water channels.

3.1 The Surface Water Transport Pathway

The major processes that cause the transport of soil particulates to surface water channels are erosion and overland flow. Channel flow then transports the eroded sediments downstream. Contaminant transport by overland flow can be by both physical and chemical mechanisms. Physical processes dominate the transport of Pu-239/240 and Am-241 by overland flow for the reasons mentioned above.

3.1.1 Erosion Processes

A thorough understanding of erosive processes on the Site is important, because small amounts of Pu-239/240- and Am-241-contaminated sediments reaching the Site surface water channels can have a significant impact on water quality. Soils are subject to erosive processes that vary in space and time. The erosive processes, driven by precipitation and overland flow, include runoff, soil detachment, transport, deposition, and sediment delivery at the downslope end of the hillslope profile (Lane et al., 1987). Definitions of some common erosion terms are included in Table 1.

Precipitation provides the energy of raindrop impact to loosen and detach soil particles from the soil surface. Rainfall runs off when the infiltration capacity and the surface storage capacity of the surface soil is reached, creating overland flow that entrains soil particles and carries them down slope (Dreicer et al., 1984 and Kidwell et al., 1997). Snowmelt usually occurs more slowly than rainfall. However, if the soil is frozen and temperatures become high, then large amounts of runoff may occur rapidly. Both rain and snow have the potential to transport Pu-239/240- and Am-241-contaminated soil across the Site landscape.

Many physical and biological factors affect soil erosion and sediment yield on rangeland watersheds. The susceptibility of a soil to erosion is controlled by various types of soil cover, including plant canopy cover, plant aerial cover, plant basal cover, plant litter, rock cover, and cryptogamic cover. Soil characteristics affecting erodibility include hydraulic conductivity (rate of infiltration), surface roughness, soil texture, bulk density, soil organic matter content, and the degree and stability of soil aggregation (Weltz et al., 1998; Gutierrez and Hernandez, 1995; Simanton et al., 1991; Dadkah and Gifford, 1980; and Blackburn, 1975).

Dense vegetation and plant residues, creating greater than 90 percent soil cover in many areas of the Walnut and Woman Creek watersheds, provide protection against erosion. Areas with less cover are interspersed throughout the watersheds. These areas and unpaved roads may account for most of the soil erosion that occurs at the Site.

Hydraulic conductivity measurements and rainfall simulation studies at the Site indicate rapid soil infiltration rates (DOE, 1995b; Fedors and Warner, 1993; Zika, 1996; Ryan et al., 1998; and Litaor et al., 1996 and 1998) and low runoff rates. However, surface water monitoring data for the Site indicate that runoff is significant.

The AME initiated research on the size distribution of water-stable aggregates of soils and sediment particles from the Walnut Creek and Woman Creek watersheds (RMRS, 1998a) to

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support the erosion and sediment transport modeling. The size distribution of the water-stable aggregates was determined and used for actinide transport calculations rather than the particle size distribution of the parent soils (i.e., sand, silt and clay) because the water-stable aggregates are transported by overland flow. Results have shown the Site soils to be well aggregated, with the majority of the soils comprised of water-stable aggregates greater than 200 microns (0.2 mm or 0.008 in) in diameter (Appendix B). The results have been used to track both sediment and Pu-239/240 and Am-241 in the modeling.

3.1.2 Overland Flow

There are two basic forms of overland flow: interrill or sheet flow and concentrated rill flow. Interrill flow occurs between rills, with water running over the soil surface in diffuse or sheet flow. Much of the energy for detachment of soil particles for transport by interrill flow comes from raindrop impact, although the proportions of detachment due to rainfall impact and surface flow depend on other factors, including slope, cover, and soil type (Ellison, 1947; Kinnell, 1985; and Quansah, 1985).

Erosion due to sheet flow is less obvious than that due to rill flow. A rill is an area on the soil surface that supports concentrated flow. A rill can be thought of as a micro-channel. Concentrated rill flow is the flow of runoff in these micro-channels. Both soil and plant growth characteristics contribute to the morphology of rills. Most of the erosion that occurs in rills is due to the energy of the flowing water (Lane et al., 1987).

3.1.3 Channel Flow

Surface water channel flow transports particulates, colloids, and dissolved species. Actinides may be associated with all of these phases. Precipitation events and batch releases from the detention ponds cause turbulent flows capable of resuspending and transporting streambed sediments off-Site. Wind can resuspend pond bottom sediments via wave action. Seasonal inversions of pond waters due to temperature stratification have also been documented in Site detention ponds. These inversions resuspend sediments from the pond bottom, which temporarily increases concentrations of several water quality constituents, including Pu-239/240 (EG&G, 1993c and DOE, 1996b). Fish, reptiles, waterfowl, and aquatic mammals also can cause particulate resuspension, stirring up bottom sediments during their daily activities.

Factors that affect particulate mobility in surface water streamflow include the following:

- Stream bed composition;

- In-stream vegetation, such as cattails, that can physically filter out the particulates;
- Diversion dams or other physical barriers that slow surface flow and enhance particle settling;
- Ice cover on ponds that prevents the resuspension of pond bottom sediments via wave action and bioturbation by terrestrial agents; and
- Hydraulic efficiency of the stream channels (e.g., slope, pool to riffle ratio, meandering, etc.).

Particulate transport occurs through combinations of the above processes and not by any single mechanism. Einstein and Gottschalk (1964) provide a good review of sedimentation in streams and reservoirs.

4.0 Model Selection

4.1 WEPP Model Selection

Several models were reviewed before the WEPP model was chosen to estimate Site runoff and erosion. Models reviewed included the following: 1) the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978); 2) the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997); 3) the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977 and Jackson et al., 1986); 4) the Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1980); and 5) WEPP (Flanagan and Livingston, 1995). All of these models have limitations. The WEPP model has the most detailed input and output of any of these models. It was determined that the WEPP model was the only one of the above models capable of producing the information necessary to meet the objectives presented in Section 1.1 of this report (RMRS, 1998c). The other models are not reviewed in this text. For specific information on the other models, the reader can refer to the citations above or review articles by Lane et al. (1987) and Weltz et al. (1998).

The AME selected the WEPP model to estimate sediment loading to channels from hillslopes. The watershed component of the model was not applicable to drainages of the size and complexity of the Walnut Creek and Woman Creek watersheds. The WEPP model sediment yield results have been coupled with the HEC-6T surface water transport model to estimate sediment movement and surface water concentrations of suspended solids and Pu-239/240 and Am-241 associated with them within the watershed channels (as discussed in Section 9). The output of both models, plus the soil water-stable aggregate data (Appendix A) and the Pu-

239/240 and Am-241 distribution estimates (Appendix B), were combined to develop a transport model for contaminants associated with the particulate phase.

4.2 HEC-6T Model Selection

Four options were identified as viable for modeling the sediment transport within the Site watersheds. Each option would model transport of the hillslope runoff and sediment, provided by the WEPP model, as point source inputs (tributaries) into the system. The four options are as follows:

1. Modeling using graphical interface and transport equations. This method would use transport equations that are on the disk provided with C. Ted Yang's book *Sediment Transport: Theory and Practice* (Yang, 1996). Each reach would need to be evaluated, and a spreadsheet would be used for input and output.
2. GSTARS, Version 2.0 – This model was developed by C. Ted Yang with the U.S. Bureau of Reclamation (USBR), Denver, Colorado (USBR, 1998). This model is public domain. This one-dimensional model utilizes the stream-tube method of transport for each cross-section. Adequate equations exist within the Generalized Stream Tube Model for Alluvial River Simulation (GSTARS), Version 2.0, model to route the types of sediment found at the Site. This model does not account for tributary inflows. Tributary inflow (hillslope sediment input) would need to be modeled as additional sediment flowing into the next reach. Modeling the tributary inflow would require a reach by reach methodology of multiple runs to model the entire system. This would be tedious and time consuming.
3. The Hydrologic Efficiency Code 6 (HEC-6) model is owned and distributed as public domain by the U.S. Army Corps of Engineers (COE) Hydrologic Engineering Center, Sacramento, California (COE, 1993). This one-dimensional model has 13 equations of sediment transport that are adequate to model the Rocky Flats channels. The model allows for multiple tributaries to enter the stream network. HEC-6 is a verified model, and no hesitations exist in using this model.
4. The HEC-6T model is owned by Tony Thomas of Mobile Boundary Hydraulics, Clinton, Mississippi. A new HEC-6T version was released in 1999. Mr. Thomas developed the original HEC-6 model while at the Hydrologic Engineering Center. Since leaving in 1993, he has continued to work on the code. The code has changed enough for him to add the 'T' to the end and identify it as a different program. Mr. Thomas added 7 additional transport equations to the code, making 21 sediment transport equations available. The added equations are the more appropriate equations to use in modeling the Site watersheds and the code allows up to 10 tributaries or branches per segment of the stream network.

Upon reviewing and researching each of these options, it was concluded that the HEC-6T model was the most flexible and could best be used to model the hydrology of the small streams on the Site. The model has a wide choice of transport equations of the types needed to precisely model the flow and sediment transport in the Site streams. The program allows for multiple tributaries and can model the loss of flow due to the ephemeral and intermittent nature of the stream system.

5.0 Description of the Models

5.1 The WEPP Model

The WEPP model was developed by the U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS), and the U.S. Department of the Interior and other cooperators. It is a new generation of process-oriented, personal computer-implemented model incorporating improvements in erosion prediction technology based on erosion mechanics, soil physics, plant science, hydrology, infiltration theory, and stochastic weather generation (Flanagan and Livingston, 1995). The WEPP model is a distributed parameter, continuous simulation computer program that estimates 1) spatial and temporal distributions of soil loss and sediment deposition from overland flow on hillslopes; and 2) sediment transport, erosion, and deposition in small channels and impoundments. Extensive model validation has been done by ARS and other cooperators (Laflen et al., 1994; Zhang et al., 1996; Flanagan and Livingston, 1995; Liu, et al., 1997; and Baffaut et al., 1998).

The WEPP model provides some major advantages over other frequently used hydrologic/erosion models. It reflects the effects of land use changes over time and space and models spatial and temporal variability of the factors affecting the surface and subsurface water quality and quantity down a hillslope or over a watershed. It can be used to assess the hydrologic or erosion potential of existing conditions or a set of proposed conditions (Savabi et al., 1995). The model was designed to assist in resource conservation decisions and in determining impacts of sediment-borne constituents reaching waterways.

Continuous simulations can be run over a period of up to 999 years. Rain can occur on any given day and may or may not cause a runoff event, depending on the rainfall, soil, and vegetation characteristics. Single storms can also be simulated. If runoff occurs, soil loss, sediment deposition, sediment delivery off the hillslope, the sediment particle size distribution, and the surface area enrichment ratio for the event are estimated. When run in the continuous mode, a wide variety of soil and plant parameters are estimated on a daily time step.

5.2 WEPP Model Components

The model includes the following components for stochastic weather generation: 1) winter processes; 2) plant processes, including growth and decomposition; 3) hydraulics, overland flow, and soil water balance; and 4) soil erosion and deposition. Input data and sources are shown in Table 2 and in Appendix A. A brief description of each WEPP model component follows.

5.2.1 Climate

The climate generator, CLIGEN, estimates daily values for rainfall amounts and durations, maximum intensities, times to peak intensity, maximum and minimum temperatures, solar radiation, wind speed and direction, and dew point using meteorological data collected at many reporting stations in each state. The user can choose a station that is representative of local climactic conditions. Alternatively, precipitation data from a study site can be used (Nicks, 1985). CLIGEN uses a single-peak storm pattern for the continuous simulation mode and for single events but can also create files for breakpoint rainfall data for single events.

5.2.2 Winter Processes

The winter processes component estimates soil frost, soil thaw, snowfall, and snowmelt. Estimated values for solar radiation, air temperature, and wind are used to drive the snow melting process (Flanagan et al., 1995). If the minimum temperature on a day with precipitation falls below 0° Centigrade (32° Fahrenheit), then precipitation occurs as snowfall.

5.2.3 Plant Growth

For rangelands, plant growth, and the combined above and below ground biomass, are simulated for the plant community using a potential growth curve, based on the ERHYM-II (Wight, 1987) and SPUR models (Wight and Skiles, 1987). Initiation of growth in the spring depends on temperature and moisture. The plant growth component also includes routines to estimate plant residue decomposition as a function of temperature and precipitation (Flanagan et al., 1995).

5.2.4 Hydrology, Overland Flow, and Water Balance

The hydrology component computes infiltration, runoff, soil evaporation, plant transpiration, soil water percolation, plant and residue rainfall interception, depressional storage, and subsurface tile drainage. The infiltration routine uses the modified Green and Ampt infiltration equation (Mein and Larson, 1973 and Chu, 1978). Runoff is computed using the kinematic wave equations or an approximation of the kinematic wave solutions (Stone et al., 1995) obtained for a range of rainfall intensity distributions, hydraulic roughness, and infiltration parameter values. The overland flow hydraulics component computes the impacts of soil roughness, residue cover, and plant cover on runoff rates. The runoff characteristics affect the flow, shear stress and sediment transport capacity on the hillslope. Water balance routines are modifications of the Simulator for Water Resource in Rural Basins (SWRRB) methodology (Williams et al., 1985 and Flanagan et al., 1995).

5.2.5 Soil Erosion and Deposition

A steady-state sediment continuity equation estimates the change in sediment load in the flow with distance downslope. Soil detachment in interrill areas is a function of the rainfall intensity and runoff rate. Delivery of sediment to rills is a function of slope and surface roughness. Detachment in rills occurs if hydraulic shear stress exceeds a critical value and the quantity of sediment in the flow is less than the flow's capacity (Foster, 1982 and Finkner et al., 1989). Deposition occurs on a hillslope when the sediment load in the flow exceeds the capacity of the flow to transport it. Soil detachment is adjusted by the effects of canopy cover, ground cover, and buried residue. The model estimates the selective deposition of different sediment size classes, the sediment size distribution leaving the hillslope, and the sediment specific surface enrichment ratio (Foster et al., 1985 and Flanagan et al., 1995).

Watershed simulations use three more components: the channel hydrology and hydraulics, channel erosion, and impoundment components. These will not be discussed, because they were not used for the current study.

5.3 WEPP Model Inputs and Data Sources

The WEPP model is a parameter-intensive model. The input parameters can be divided into those that are "measurable" and those that are "derived." Measurable parameters are estimated from Site data or from the literature. For the WEPP model these include input data on local weather, soils, topography, vegetation, and hillslope geometry. Once these parameters are estimated, they do not change during the course of the model calibration. Derived parameters are those used to calibrate the model to observed erosion and runoff data from the study area. The model is very sensitive to these parameters, which include the following: 1) the effective hydraulic conductivity (the rate at which water infiltrates into the soil during precipitation events); 2) the interrill erodibility (the susceptibility of a soil to erosion by raindrop impact and

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diffuse sheet flow); 3) the rill erodibility (the susceptibility of a soil to the formation of concentrated flow paths or rills); and 4) the critical shear stress or the force per unit area of soil surface that the flowing water must exceed to detach particles of soil.

Data for this modeling effort come from Site monitoring and remediation programs, AME-associated research, U.S. Geological Survey (USGS) publications, U.S. Soil Conservation Service Soil Surveys, the WEPP technical documentation, the WEPP climatological database, and various published articles and theses. Data input requirements, sources and values are listed in Table 2 and discussed in greater detail in Appendix A. Input files used in the modeling effort are included in Appendix E. The model input files include the following:

- The **Climate file (*.cli)** includes daily precipitation amounts, durations and intensities, temperatures, wind speed and direction, solar radiation, and dew point, which are all measurable input parameters. Weather data for the Site and from the WEPP/CLIGEN database for Fort Collins were used to create the climate file for the 100-year simulation. Single storm climate files were created for six design storms using site data and estimates from the Rocky Flats Plant Drainage and Flood Control Master Plan (EG&G, 1992b).
- The **Slope file (*.slp)** includes hillslope length, width, slope, and orientation, which are all measurable data inputs. These parameters were estimated from the Site's GIS database.
- The **Soil file (*.sol)** includes texture, organic matter content, percent rock fragments, and cation exchange capacity, which are measurable parameters derived from the Site's soil database. This file also contains the important derived parameters used in model calibration, hydraulic conductivity, interrill and rill erodibility factors, and the critical shear stress.
- The **Plant Management file (*.man)** includes information on the plant communities found in the Buffer Zone at the Site, the length of the growing season, soil cover and roughness, and residue decomposition. These are all measurable values, which, once set to produce output that describes the Site rangeland environment, are not changed. The management file has many parameters that are given in Appendix A.

5.4 WEPP Model Output

WEPP output comes in varying degrees of detail. The most important output for this study defines the locations along the hillslopes where soil is eroded or redeposited on the hillslope at intervals of 1 percent of the length of the overland flow element (OFE). This feature of the model, which delineates erosion and deposition areas, has been used for determining where actinide-contaminated soils will move and how much actinide yield is input to the stream channels at the bottoms of the hillslope profiles. This is the feature that makes WEPP the erosion model of choice for tracking contaminant movement due to erosion.

WEPP has the capability to generate a tremendous amount of output for simulated climate characteristics, vegetation growth and decomposition, soil and soil water, runoff, erosion, and other variables. Output is available for plant and soil parameters for the duration of the simulation. WEPP model output also includes summaries for both multi-year and single-storm simulations, by event, month, year, or average annual periods of precipitation, runoff, erosion, sediment movement and deposition on the hillslope, sediment leaving the base of the hillslope, and particle size distributions of the detached sediment.

The portions of the summary file that were useful for this study include the following:

- The total number of storms, total precipitation, and precipitation amounts for snow versus rain;
- A breakdown of the predicted runoff for rain storms versus snow melt;
- The amount of erosion that occurs every 1 percent interval down the hillslope by OFE; and
- Sediment yields and particle size distribution of the sediment leaving the hillslope profile.

The summary file contains the annual average runoff and erosion values for the simulation period, which can range from a single storm up to continuous simulation of 999 years. For this study, both a 100-year continuous simulation and single design storms were run for each hillslope. Therefore, the summary files contain either the 100-year annual average values or single event values for runoff and erosion.

5.5 Site Model Structure for WEPP Simulations

The modeling process, including the sediment transport model, from identification of hillslopes to estimation of surface water concentrations of Pu-239/240 and Am-241 is shown in

Figure 3. The Site WEPP erosion model is separated into three watersheds: 1) Woman Creek; 2) the SID; and 3) Walnut Creek (Figure 1). Each watershed has been divided into hillslopes based on drainage patterns.

Figure 4 shows the hillslope delineations for all three watersheds.

Each hillslope is divided into OFEs that are distinguished by specific soil and vegetative cover characteristics. OFE boundaries were determined by boundaries between different soil groups based on the Site soil map (

Figure 5) and/or by changes in vegetation type based on the Site's vegetation map (

Figure 6). Soil and vegetation parameters used in the model are discussed in detail in Appendix A.

Figure 7 through Figure 9 show the OFE boundaries and slope transects for each hillslope, in each watershed.

The slope of each OFE was determined using geographic information systems (GIS). Linear transects, perpendicular to the topography, were drawn electronically from the top to the bottom of each OFE on 2-foot interval contour coverages, such that the transects visually represent the overall topography of the OFEs (

Figure 7 through Figure 9). Next, GIS techniques were used to provide several instantaneous slope values at points on the transects. The transect slope values were averaged laterally across each OFE to provide data that describe the average land surface profile in each OFE. Hillslope and OFE dimensions, soil types, and vegetation/habitat types are listed in Table 3 through Table 5 for each watershed.

The hillslope lengths and areas were also determined using the linear transects on each hillslope (see Appendix A and

Figure 7 through Figure 9). Typically, three or more transects were drawn on the hillslopes, and the average length was determined to represent the hillslope length. The computed hillslope lengths were divided into the hillslope areas, as determined by GIS methods, to compute the hillslope widths. This was done to preserve the measured hillslope lengths, because slope length is a sensitive erosion modeling parameter. Although the hillslopes are irregularly shaped in real space, WEPP forms rectangular hillslopes in virtual space for the model computations. The WEPP hillslopes are two-dimensional surfaces that vary in length and width and along the vertical dimension (the slope) but do not vary laterally across the slope. The AME project team developed techniques to convert WEPP output back into data that can be mapped using GIS to show the distribution of erosion across the watersheds (Appendix B).

The hillslopes were delineated to provide reasonable resolution for estimation of runoff and erosion without making the model unnecessarily complex. Some of the hillslope lengths exceed the recommended lengths for WEPP. Therefore, contributors to WEPP at the ARS

Southwest Watershed Research Center in Tucson, Arizona, were consulted to review the hillslope and channel delineations. Their assessment concluded that the hillslopes and channels were reasonable (J. Stone and M. Weltz, personal communication, 1998). The effects of hillslope length on runoff and soil loss are shown in Appendix A. Mokhothu (1996) showed that increasing the complexity of the WEPP watershed model beyond a point did not improve the accuracy of the model predictions for a small rangeland watershed.

5.6 The HEC-6T Model

HEC-6T is a recently updated version of the HEC-6 model originally developed by the COE. HEC-6T allows for up to 100 tributary inflows to the main channel, which was crucial for modeling the Site watersheds. HEC-6T also includes additional sediment transport equations (when compared to HEC-6), some of which are applicable to small streams like those at the Site.

HEC-6T was validated by the COE and the USGS prior to its release. The model has been used to estimate sediment transport characteristics in rivers largely for the purpose of engineering design and maintenance of waterways and dams. It can also be used for estimating contaminant yields in streams, provided that the contaminant is associated with the sediment phase. HEC-6T combines flow computation via the Manning Equation with sediment suspension and deposition via 15 different user-selected methods. For this study, Yang's equation was selected based on the advice of Dr. Pierre Julien (Colorado State University) and Ernie Pemberton, P.E. (WWE)—both recognized experts in sedimentology.

5.7 HEC-6T Model Input

The HEC-6T model requires the following input data (which were obtained from field measurements): 1) Site monitoring data; 2) WEPP output; and 3) Site mapping and reports. Coefficients used to adjust the channel erosion rates are not listed here. The channel sediment available for resuspension (erosion) was set to 0 for the current study. This was done in order to track the hillslope sediments in the drainages and calculate surface water concentrations based only on inputs of contaminated soil. The channel erosion parameters in HEC-6T can be adjusted to produce reasonable channel erosion estimates. All of the HEC-6T models for each hydrologic event in each watershed are contained on the CD-ROM provided in Appendix E.

Channel geometry, bed sediment grain-size distribution, and channel roughness data were collected in the field. These data were supplemented by existing Site data, such as 2-foot contour mapping, floodplain mapping, and sediment monitoring data. All of the SID channel cross-section data were obtained from a previous HEC-2 modeling study by Diana Woods (RMRS Engineering) in 1992 (EG&G, 1993d).

For each receiving stream, channel cross-sections were selected for measurement wherever the channel geometry changed substantially. The cross-sections were measured by stretching a tape measure perpendicular to the channel with each end of the tape located at approximately the same elevation. The distance from the channel bottom to the tape was measured with a surveying rod at as many locations as needed to represent the shape and depth of the channel cross-section adequately. The cross-section locations were mapped in the field. These locations were then mapped by GIS methods, and the linear distance between each cross-section location was determined using GIS.

The HEC-6T model is not sensitive to subtle changes in the channel geometry. Therefore, some cross-sections were simply identified as being geometrically similar to previously measured cross-sections, which streamlined the field data collection and model building process. Where significant changes in channel roughness occurred, such as the boundaries between earthen channels and rip-rap or concrete weirs, duplicate cross-sections with the same geometry were input into the model, and each cross-section was assigned an appropriate roughness for the type of channel material present. Where appropriate, data from 2-foot topographic mapping were used to extend the field cross-section data up to the 100-year floodplain elevation per the floodplain maps in the Rocky Flats Drainage and Flood Control Master Plan (EG&G, 1992b).

Pebble-count data were collected at locations believed to be representative of the average grain-size distribution in the channels. The pebble counts consisted of randomly selecting pieces of bed material over 100 contiguous paces down the stream beds per the method described by Wolman (1954). Observations of stream vegetation types, canopy height, and cover were recorded at the cross-sections to provide guidance for roughness coefficient selection for each transect. An example field data sheet and the pebble-count data tables and distribution curves are provided in Appendix C.

Hydrologic and sediment inputs to the model will be discussed in Section 6, which outlines methods used to integrate the HEC-6T model and the WEPP model.

5.8 HEC-6T Model Output

The HEC-6T model output is packaged in a large text file in an ASCII format that can be read into word processors and spreadsheets. Output data for flow (cubic feet per second [cfs]), water yield (acre feet [ac-ft]), and sediment yield (tons/day) may be printed for each time step during the runoff event. Cumulative channel erosion depth (feet [ft]) and hydraulic conditions are also estimated at each cross-section.

A summary table is produced in the output file to show the total sediment yield (tons) passing the model cross-sections and the total amount of sediment deposited in the channel reaches between the cross-sections (cubic yards [yd^3]). Average suspended sediment concentrations were calculated for selected locations in each watershed by dividing the total sediment yield passing the cross-section by the total water yield at the cross-section.

Each model was run for an event with no channel erosion to evaluate transport of the hillslope sediment yields. Therefore, the amount of the sediment that comes from the hillslopes can be tracked in the stream channels, and areas of deposition or sinks can be determined.

The output from the HEC-6T model was then joined with the WEPP sediment and Pu-239/240 and Am-241 hillslope yields to estimate surface water concentrations of total suspended solids (TSS) and actinides.

5.9 HEC-6T Site Model Structure

Several assumptions must be made for each watershed model, based on field observations or standard engineering practices. General assumptions standard to each watershed include the following:

- Channel roughness for the stream bed, left and right banks, and left and right over-banks (looking downstream);
- Depth of bed material available for erosion;
- Percentage of bed area available for erosion;
- Sediment concentration in the baseflow;
- Tributary runoff and associated sediment concentrations from industrialized areas obtained from monitoring data and the Rocky Flats Plant Drainage and Flood Control Master Plan; and
- Negligible infiltration (loss) of water from the channels.

Yang's equation computes total load, comprised of both suspended load and bed load. The equation contends that the rate of sediment transport in an alluvial channel is primarily governed by the rate of expenditure of potential energy per unit weight of water, i.e., the unit stream power (Yang, 1996). To determine total sediment concentration, Yang considered a relation between the following relevant variables:

$$C_t,\ VS,\ V_{cr}S,\ u_*,\ \nu,\ \omega,\ d$$

Where:

C_t = total sediment concentration, with wash load excluded (in milligrams per liter [mg/L] by weight);

VS = unit stream power;

$V_{cr}S$ = critical unit stream power at incipient motion;

u_* = shear velocity;

ν = kinematic viscosity;

ω = fall velocity of sediment; and

d = median particle diameter.

Using the Buckingham π theorem, C_t can be expressed in a dimensionless form. From laboratory flume data and running multiple regression analysis, Yang found the best form of the equation to be as follows:

$$\log C_t = 5.435 - 0.286 \log \frac{\omega d}{\nu} - 0.457 \log \frac{u_*}{\omega} + \left(1.799 - 0.409 \log \frac{\omega d}{\nu} - 0.314 \log \frac{u_*}{\omega}\right) \log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right) \quad (1)$$

Yang's equation was found to work satisfactorily both for laboratory and field data. For this study, it was assumed that the bed load component of the total yield was negligible when compared to the suspended load. Further HEC-6T modeling using other equations, such as the Ackers and White equation and Einstein's equation, would be useful for establishing a range of expected sediment yields (Garde and Ranga Raju, 1985).

5.9.1 The SID

The following assumptions were made for the SID watershed HEC-6T model:

- All runoff was contained within the SID channel with no overflow;
- No bed erosion was allowed;
- The depth of the erodible channel was set to 0 feet;

- Channel roughness was not assumed to be uniform throughout the channel with Manning's n-values set from 0.02 to 0.08 for the bed, 0.04 for the banks, and 0.05 for the over-bank areas;
- Baseflow sediment concentration was set to 0 milligrams per liter (mg/L) at 42.5 L/s (1.5 cfs) and 300 mg/L at 1,416 L/s (50 cfs);
- Sediment concentrations in runoff from industrialized areas of the Site were set to the average concentrations measured in stormwater runoff from gaging stations GS21, GS22, GS24, and GS25, which measured runoff water quality from 1995 to 1997 (data for these stations are in Appendix E); and
- Runoff from industrialized areas was determined by computing the runoff coefficient for each gaging station for the May 17, 1995, event and then applying the coefficient to the precipitation depths for the design storms. The duration of runoff was also estimated from the gaging data by computing the ratio of the runoff duration to the precipitation duration for the May 17, 1995, event. The ratio of these durations was then applied to the rainfall durations of the design storms. From these data, triangular unit hydrographs were computed for each IA hillslope tributary to the SID.

5.9.2 Woman Creek and Mower Ditch

The following assumptions were made for the Woman Creek watershed HEC-6T model:

- Minimal tributary inflow comes from the Woman Creek drainage area located west of the South Boulder Diversion Canal (this assumption is violated for extreme events, when runoff from Highway 93 and the Kinnear Ditch drainage enters the watershed [Figure 1]);
- Baseflow sediment concentrations were set to less than 100 mg/L;
- Channel roughness was assumed to be variable throughout the watershed. Manning's n-values were generally set to 0.06 for the bed, 0.04 for the banks, and 0.05 for the over banks in Mower's Ditch; 0.04 to 0.09 for the bed, 0.025 to 0.04 for the banks, and 0.05 for the over banks in Woman Creek; and 0.10 for all portions of the C-1 dam;
- No bed area was available for erosion (the channels were set to 0 feet of erodible depth);
- Overflow from Mower Ditch was assumed to remain in its channel and not enter the Woman Creek channel to simplify the model (overflow might actually occur for large [e.g., 100-year] events); and
- Although shallow flooding on the Pond C-2 emergency spillway would likely occur for the 100-year event (and possibly smaller events), it was assumed that the pond retained all water tributary to it with no contribution to Woman Creek. This is a reasonable assumption if the pond starts out empty at the beginning of the storm.

5.9.3 Walnut Creek

The following assumptions were made for the Walnut Creek watershed HEC-6T model:

- Minimal tributary inflow comes from off-Site areas via the McKay Ditch (McKay Ditch baseflow and sediment concentrations were obtained from average values for gaging station SW998);
- Baseflow sediment concentrations were set to less than 100 mg/L;
- South Walnut Creek suspended sediment concentrations for runoff from the IA were set to the average of TSS concentration at gaging station GS10. North Walnut Creek suspended sediment concentrations for runoff from the IA were set to the average TSS concentration at gaging station SW093 (Appendix E). Hillslope 77 sediment concentrations were set to the average concentration measured at gaging station SW091;
- Channel roughness was assumed to be variable throughout the watershed. The Manning's n-values range from 0.03 to 0.08 for the bed, 0.03 to 0.07 for the banks, and 0.05 to 0.09 for over bank areas, and 0.10 for all portions of the cross-sections of the A-series and B-series detention dams;
- No bed area was allowed to be available for erosion (erodible bed depth was set to 0 feet);
- At the A-series and B-series bypasses, the flow is split per the scheme shown in Table 6 to route a portion through the bypass and the overflow through the ponds;
- For events larger than the 2-year event, a high percentage of the flow from the Central Avenue Ditch traverses the East Trenches Area to South Walnut Creek. The flow has formed a headcut over Hillslopes 69 and 75 prior to entering Walnut Creek. The suspended sediment concentration for this water was assumed to be the same as the WEPP-estimated concentration for Hillslope 74, and the water is routed into South Walnut Creek upstream from Pond B-5. For large events, mass wasting of the hillslope could actually occur, and this material would travel to South Walnut Creek. This phenomenon was not accounted for in the model; and
- The A-series and B-series detention ponds were assumed to be full at the start of the runoff events. No principal outlet works are open on the dams. The flow is routed over the emergency spillways. Therefore, actual yields for the 2-year, 10-year, and possibly the 100-year event are expected to be much lower than predicted herein, as the ponds would be able to contain most, if not all, of the water tributary to them for these storms. Routing the flow over the emergency spillways provides a worst case scenario for sediment and associated actinide transport. HEC-6T would not run for the entire watershed if the ponds were not modeled in a full condition.

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6.0 Integration of the WEPP and HEC-6T models

Separate WEPP and corresponding HEC-6T models were built for the SID, Woman Creek, Mower Ditch, and Walnut Creek watersheds. The models were used to estimate sediment and associated actinide transport for six events: 1) 40.8-mm, 6-hour, 2-year return interval; 2) 31.5-mm, 2-hour, 2-year return interval; 3) 62.3-mm, 6-hour, 10-year return interval; 4) 97.1-mm, 6-hour, 100-year return interval; 5) 74.9-mm, 11.5-hour event similar to the actual May 17, 1995 event (11-year return interval); and 6) 35-mm, 11.5-hour, low intensity event, with an approximate one-year return interval.

The rainfall distributions during the 6-hour and 2-hour events were obtained from the Rocky Flats Drainage and Flood Control Master Plan (EG&G, 1992b). This rainfall distribution, derived from the Colorado Urban Hydrograph Procedure (CUHP), is shown in Figure 10. For this distribution, a majority of the rainfall occurs in the first hour of the storm. The rainfall distributions for the two 11.5-hour events were based on Site rain gage data for the May 17, 1995, event.

The storms were run in the WEPP single storm mode simulation for each Site hillslope. The runoff, peak discharge, sediment yields, and particle size distribution output from WEPP was formatted for HEC-6T input. The integration of the two models is described below.

The WEPP hillslope sediment yields were modeled as tributary inflows to the main stream channels. In selected stream reaches, the runoff and sediment yields from adjacent hillslopes were added together to condense the number of tributary inflows to the channels. This made the models logistically easier to program and run while maintaining adequate representation of the natural system.

Figure 4 shows the hillslopes that comprise the structure of the Site WEPP models.

Figure 11, Figure 12, and Figure 13 are schematic representations of how the WEPP hillslope sediment and water yields were routed into the main channels in HEC-6T.

The channel cross-section identifiers in Figures 11 through 13 are the number of meters from the outlet of a stream segment for Woman Creek, Walnut Creek, and the Mower Ditch. However, for the SID, the channel cross-sections are the number of meters from the most upstream point on the SID. The SID HEC-6T model was developed from the previous HEC-2 model (EG&G, 1993d), and the cross-section identifiers from the HEC-2 model were maintained in HEC-6T.

6.1 Model Integration Methods

Integrating WEPP and HEC-6T was accomplished by the following procedure:

- HEC-6T runoff hydrographs for each tributary inflow (hillslope) were created using the WEPP-estimated "peak runoff" (i.e., peak discharge) and "runoff" (i.e., total yield) values;
- The peak runoff and runoff values were used to compute triangular unit hydrographs with the peaks occurring at one-sixth of the runoff duration for the 6-hour events, one-fourth of the runoff duration for the 11.5-hour events, and one-fifth of the runoff duration for the 2-hour event. The triangular distributions were selected to match the rainfall intensity distributions;
- The time step for the runoff portion of each HEC-6T model was set according to the shortest tributary runoff duration within a watershed. The time step was adjusted until each tributary in HEC-6T produced a runoff yield that matched the WEPP model output to within $\pm$ 10 percent;
- Baseflow in the main channel, upstream from all of the tributary inflows, was set as low as possible to simulate observed conditions based on monitoring data from Site stream gages;
- Where two or more hillslopes contributed flow and sediment load to the same point in the main channel, the flows for each hillslope were summed using the triangular unit hydrograph method;
- Sediment loads were calculated for each tributary inflow using a triangular unit hydrograph methodology similar to that described above for runoff;
- The WEPP-estimated total sediment yield and the runoff duration calculated in the unit hydrograph procedure (above) were used to compute the peak sediment load for each tributary inflow. The WEPP-estimated peak runoff rate (in cubic feet per second) and the peak sediment load (in short tons/day [short ton = 2,000 pounds]) were then paired for each design storm, thereby forming the data needed for the HEC-6T sediment discharge curve for each tributary inflow;
- Sediment particle size distributions for five classes and the estimated specific gravity of the tributary sediment were obtained for each hillslope from WEPP output; and
- The WEPP particle size estimates were then adjusted from the five particle sizes from the WEPP output to the nine sizes required as input to HEC6-T by fitting the WEPP data to a log-normal distribution determined from data on Site surface soils. These data are found in the CD-ROM in Appendix E.

WEPP was not designed to estimate runoff and sediment yield from improved, paved areas. Therefore, estimated runoff yields and peak discharge rates were obtained from IA sub-basin gaging stations tributary to the SID and Walnut Creek. Corresponding sediment concentrations were obtained from stream monitoring data from Site gaging stations GS10,

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SW091, SW093, SW998, GS21, GS22, GS24, and GS25. These data are reported in Appendices A and E.

Discussion of the HEC-6T model calibration and comparison of the results to measured data and other studies are contained in Appendix C. Supplementary data and methods used to develop the models are also contained in Appendices B and C.

6.2 Summary of AME Modeling Data Quality Objectives

The following is a summary of the DQOs that have been identified to adequately substantiate the quality of the erosion modeling effort. The DQOs identified in this summary are the categories of applicable requirements that have been excerpted from "Fiscal Year 2000 Actinide Migration Evaluation Data Quality Objectives, Revision 2." The erosion modeling effort is an important component of the overall regulatory closure of the Site and may impact action levels and remedial approaches. Additionally, the modeling results will undergo intense scrutiny by the Site, stakeholders, and regulatory agencies. Therefore, the stringent application of the applicable DQOs to the erosion and sediment modeling effort is essential. The DQO categories applicable to the erosion modeling effort include sensitivity/uncertainty analysis, calibration, and verification/validation activities, which are described below.

6.2.1 Sensitivity and Uncertainty Analysis

Model sensitivity and uncertainty analysis may encompass all input parameters, including: 1) "derived" parameters (those that may be varied in the calibration process); and 2) "measured" parameters (those that are estimated and then left fixed throughout the simulations). The sensitivity and uncertainty analysis has been performed in accordance with the AME DQO criteria. A description of these activities and results of the evaluations can be found in Appendices A (Section A3), C, and D.

6.2.2 Calibration

Model calibration is an iterative process of parameter adjustment such that model output satisfactorily estimates a set of real-world data. A calibration of the erosion model has been performed in accordance with the AME DQO criteria. A description of the erosion and sediment transport model calibration processes and comparisons of predicted values to Site monitoring observed data are found in Appendices A and C, respectively.

6.2.3 Model Verification/Validation

The process of model verification/validation (the assessment of model adequacy) includes assessing all aspects of the model's assumptions, inputs, outputs, sensitivities, and uncertainty, with particular emphasis on calibration results and limitations. Verification / validation of the erosion model has been performed in accordance with the AME DQO criteria. A description of the verification/validation activities, including the results of comparisons to observed Site monitoring data, can be found in Appendices A and C. Uncertainty associated with the model predictions is addressed in Appendix D.

7.0 Estimation of Erosion and Actinide Mobility

The long-term, WEPP-estimated erosion rates were evaluated by comparing WEPP output for individual storms to monitoring data collected for similar types of events. WEPP predicts the quantities of runoff and sediment delivered from the hillslopes to the stream channels. Site monitoring data includes stream discharge measurements and suspended sediment concentrations that were used to estimate measured runoff and sediment yields. The WEPP-estimated yields are compared to the measured yields in Appendices A and C.

7.1 100-Year Simulation Erosion Results

A 100-year continuous simulation was run for each hillslope. The 100-year annual average runoff and erosion output values from the WEPP summary output files were mapped to generate the 100-year annual average erosion maps and 100-year annual average Pu-239/240 and Am-241 mobility maps. Results for individual storms from the 100-year continuous simulation were retrieved from the event output files for comparison to measured data to assess model performance (Appendix A).

The predicted 100-year annual average values of runoff and erosion for each watershed and hillslope are shown in Table 7 through Table 9. The average annual erosion rates represent the total amount of runoff and erosion over the 100-year simulation divided by 100. Annual erosion rates for the three watersheds varied in the order; the SID at 0.384 T/ha (0.171 t/ac) > Walnut Creek with 0.324 T/ha (0.145 t/ac)> Woman Creek at 0.221 T/ha (0.099 t/ac). The predicted average annual erosion depth on a Site-wide basis is about 0.02 mm to 0.04 mm, but the annual erosion depths will vary across the Site, as demonstrated by the sediment yield estimates in Figure 14. Runoff as a percentage of the annual rainfall (runoff coefficient) was predicted to be highest in the SID (6 percent) and lowest in Walnut Creek (3.5 percent). These values are consistent with the Loading Analysis Report (RMRS, 1998b) results which estimated runoff coefficients from Site stream gaging and precipitation data to be 0.08 to 0.14 (8 to 14 percent). The measured runoff coefficients are positively skewed because they are for a short period of observation, include the high runoff yields of Spring of 1995, and they do not account for baseflow (i.e., they do not separate baseflow from direct runoff or storm flow). The runoff coefficients predicted by the WEPP model compare favorably with the Loading Analysis results, ranging from 3.5% to 6%, but the WEPP simulations are for direct runoff only and do not include the baseflow component.

Table 7 through Table 9 show average soil loss for all hillslopes modeled. The data show that predicted erosion on hillslopes follows the order, improved gravel roads > hillslopes with paved areas > hillslopes with improved gravel roads > hillslopes with unimproved roads > grazed hillslopes >minimally disturbed hillslopes. Hillslopes that include an improved road as an OFE were predicted to have 1 to 10 times more sediment yield than undisturbed hillslopes and accounted for 29 to 49 percent of the estimated total annual yields for each watershed. The grazed, vegetated hillslopes did not produce nearly as much sediment as hillslopes with roads. The presence of improved or unimproved gravel or "dirt" roads have a significant impact on erosion and water quality. Improved gravel roads, which are composed of sand and gravel road base combined with some finer materials, are responsible for 0.4 to 8 percent of the total annual yields in each watershed. The gravel roads comprise only a small fraction of the total area of the watersheds, but the erosion rates are much higher.

These results present a strong argument for revegetating the Site's firebreak roads at regulatory closure. The potential benefit of revegetation is a reduction of runoff and a decrease in sediment transported in Site streams. The above data suggest a reduction in the sediment contribution by the roads of up to 98 percent and up to a 25 percent reduction in total sediment yields, if the roads are properly revegetated. A revegetated road scenario will be investigated in FY01.

The great majority of the erosion is due to large, infrequent storms and the average values do not convey the very large variation in annual values of runoff and erosion due to variation in precipitation from year to year. The annual erosion estimates presented in Figure 14 (a) for the SID watershed vary from a minimum of 0.01 T/ha (0.004 t/ac) to a maximum of 3.54 T/ha (1.58 t/ac) for the 100-year simulation. The large standard deviation (greater than the mean value) is indicative of the influence large infrequent events have on the average value. The year, 1995, was a very wet year by Colorado standards and the May 17, 1995 storm had a return period of about 12 years (8 percent chance of occurrence in any year). The annual rate of soil loss predicted from the 1995 meteorological data for the Site is 0.38 T/ha (0.17 t/ac), equal to the predicted 100-year annual average. Figure 14 (a) indicates that soil losses more than double the average can be expected about 16 years out of 100 years or about once every 6 or 7 years. Figure 14 (b) compares the 100-year average erosion rates to those for the single storm events for the SID hillslopes. The 100-year average is very similar to the events with a 10- to 12-year return interval.

Figure 15 (a) and (b) present runoff (a) and erosion (b) data from the 100-year simulation for the SID for hillslopes, grouped by land use. Runoff and erosion occur infrequently on the undisturbed and partially-disturbed hillslopes at the Site. The predicted runoff for the hillslopes increases as the degree of disturbance increases. WEPP predicts that approximately 30 mm of precipitation is required in a single event to generate significant runoff and erosion on most undisturbed hillslopes, while those with unimproved roads and paved areas respond at about 20 mm of precipitation. The variance among hillslopes is due to differences in slope steepness and length, amount of disturbance (e.g. roads, etc.), vegetation type, and antecedent moisture conditions, which affect the soil saturation. The high infiltration rates of Site soils, combined with the semi-arid climate, cause runoff and erosion to occur mainly from large events or during wet periods when high levels of soil saturation increase runoff.

Average monthly runoff and erosion rates predicted by the WEPP model are shown in Figure 16 and follow the precipitation pattern for the Site (Figure 2). April and May typically have the highest average monthly precipitation, but the model predicts May and June to have the highest runoff and erosion rates. Much of the runoff in April is due to snowmelt from large, intense spring snow storms, which is not as erosive as rainfall occurring in May and June.

The 100-year average erosion rates for each hillslope were mapped using GIS. A detailed description of the methodology used to generate the soil mobility maps from the WEPP output data, using GIS, is included in Appendix B. Figure 17 shows the erosion-prone areas and average erosion rates for the 100-year simulation predicted by WEPP for the three watersheds. The soil mobility map shows that there are certain areas that are more susceptible to erosion. Three important areas, because of their potential impacts on surface water quality, are the following: 1) SID hillslopes 15, 16, 17, 18, 19 and 20 to the southeast of the 903 Pad Area; 2) the south side of Woman Creek, just above and below Pond C-1; and 3) Walnut Creek hillslope 39 to the east of Pond B-5. These hillslopes and some draining to No Name Gulch are predicted to be areas of higher erosion compared to other hillslopes on the Site. The simulated long-term annual erosion rates are consistent with rates determined for similar rangeland areas. The simulated annual erosion rates for the Site range from below 0.03 to above 0.4 T/ha for grasslands and from about 4 to over 13T/ha for improved gravel roads. By comparison, Toy and Hadley (1987) report an average erosion rate of 0.085 T/ha for grasslands in the United States, and Dunne and Leopold (1978) published erosion rates for roads ranging from 3.5 to 24 T/ha. The significance of these erosion rates on the movement of Am-241 and Pu-239/240 is summarized in Section 8.2.

7.2 Single Storm Simulation Erosion Results

Evaluation of runoff and erosion for six design storms of varying intensity, duration, and return interval was conducted in the WEPP single-storm mode. The design storms evaluated were as follows:

- A 31.5-mm, 2-year, 2-hour event (per the Drainage and Flood Control Master Plan);
- A 40.8-mm, 2-year, 6-hour event (source same as above);
- A 62.3-mm, 10-year, 6-hour event (source same as above);
- A 97.1-mm, 100-year, 6-hour event (source same as above);
- A 74.9-mm, 11-year, 11.5-hour event (similar to the May 17, 1995, event); and
- A 35-mm storm with the same rainfall distribution as the May 17, 1995, event.

The design-storm precipitation distributions were obtained from the Rocky Flats Plant Drainage and Flood Control Master Plan (EG&G, 1992b). Site rainfall distributions for very intense storms with a majority of the rainfall occurring in the first hour, derived from the CUHP, are shown in Figure 10. The design storms were selected to represent specific return intervals to assign a probability of occurrence to the erosion and sediment yields associated with each storm. The reciprocal of the return interval is the probability that the event will occur in any year (e.g., annual probability of the 100-year event is 1 percent).

The WEPP single-storm mode was used to model the design-storm events. Soil saturation and vegetation must be properly adjusted to use the WEPP single-storm mode accurately. Soil saturation for the intense storms was set to the average dry-period soil saturation predicted by WEPP for all OFEs for the intense storms (the first four design storms listed above). The intense storms represent convective thunderstorms that occur in dry summer months along the Front Range. A 15-year continuous WEPP simulation, which included the Site data for 1995 for the last year of the simulation, provided data to compute the average soil saturation during dry weather periods (29.7 percent). The soil saturation on May 16, 1995, was extracted for every OFE, on every hillslope, and special soil files were made with these saturation values for the May 17, 1995, event (about 50 to 70 percent). These same soil saturation values were used for the 35-mm storm.

The vegetation and soil cover input data were adjusted for the single-storm mode runs. The sensitive soil cover and vegetation cover parameters were adjusted to within one standard deviation of the WEPP 100-year simulation average values for the single-storm modeling. This method standardized the WEPP-vegetation growth and soil cover for all of the events modeled.

WEPP must be run in the single-storm mode to map the erosion from specific hydrologic events. The single-storm mode produces a summary output file that lists the erosion rate by distance down the hillslope. These data were formatted for mapping using the GIS techniques described in Appendix B.

Sediment yields in the continuous and single storm simulations presented in Table 10 through Table 12 and Figure 14 (b) generally follow the sequence, 100-year, 97.1-mm (6 hr) event > 10-yr, 62.3-mm (6 hr) event > 100-year continuous simulation > 11-year, 74.9-mm (May 17, 1995, 11 hr) event > 2-year, 40.8-mm (6 hr) event > 2-year, 31.5-mm (2 hr)event > 1-year, 35-mm (11.5 hr)event. Improved roads were an exception; the highest soil loss rates were for the continuous simulation; and the May 17, 1995, event was higher than the 10-year event.

The erosion results for the 100-year, 6-hour event are mapped in Figure 19 through Figure 21. Erosion rates are greater for the 100-year event than for the 100-year average erosion rates (Figure 14 (b) and Table 10 through Table 12) on all hillslopes except the improved roads. The 100-year erosion maps were designed to identify areas that are susceptible to erosion for extreme events and are intended as planning tools.

The AME produced erosion maps for all six SID design storms (Figure 22 through Figure 26), because of the importance of soil contamination, remediation, and management in the SID watershed, especially near the 903 Pad Area. Very little erosion is shown on the low intensity 35-mm event map, which is consistent with field observations of little to no overland flow and erosion during most wet spring-time events. The series of event maps for the SID demonstrates increases in erosion in intensity, extent, and distribution on the hillslopes for progressively intense events. The maps are important planning tools for determining areas that will need to be managed for long-term erosion control after Site regulatory closure.

7.3 Actinide Mobility Results

A goal of the AME Conceptual Model is to obtain rates of actinide movement from soils to other environmental media via known natural processes. In the Conceptual Model soil erosion and sediment transport processes have been hypothesized to be the most important modes of actinide transport across and off-Site. The rate of actinide movement across the landscape by soil erosion due to overland flow is an important parameter for long-term planning of Site management. The rates of Pu-239/240 and Am-241 movement with eroded sediments predicted by combining the WEPP modeling results with the kriging analysis are shown in the actinide mobility maps in Figure 27 through Figure 42. The maps estimate the amount of actinide movement per unit area, but not the distance moved. A discussion of how these maps are created using GIS techniques is in provide in Appendix B.

The actinide mobility maps are tools for guiding remediation and management decisions; remediation goals for Pu-239/240 and Am-241 that will protect surface water-quality can be developed based on the maps. Some soils with levels of actinides higher than the modeled cleanup level may not be in erosion-prone areas, and will not impact surface-water quality. The actinide mobility maps are designed to be used to target areas that are contaminated, and have a high risk of contaminating other resources. They can be used in conjunction with other methods to optimize remediation and environmental management decisions.

Actinide mobility can be expressed in a variety of units. The basic unit used in this report is picocuries per square meter (pCi/m^2), which can be modified in several ways depending on the goals and the simulation from which the estimate is developed. In the case of the 100-year simulation the units are $pCi/m^2/year$ or per 100 years. The units could also be expressed as $pCi/m^2/mm$ of precipitation, runoff, or erosion. Probabilities can also be used to modify the basic units. The 100-year event mobility maps (Figure 29 and Figure 30 Figure 35 through Figure 38, and Figure 41 and Figure 42) all express the number of pCi/m^2 that have 1 percent probability of being mobilized from an area in any year. The methods developed by the AME erosion modeling project to predict actinide mobility and estimate actinide concentrations in surface water are discussed in Appendix B.

7.3.1 SID Watershed Actinide Mobility

The highest estimates for actinide movement are in the eastern third of the SID watershed because of the contamination from the 903 Pad Area. The area is also characterized by steep slopes with access roads and disturbed areas that increase runoff and erosion. The 100-year

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average Pu-239/240 mobility map for the SID (Figure 27) shows that there are two main problem areas in the watershed where actinide mobility is relatively high. These areas coincide with the areas with the highest erosion rates, located just southeast of the 903 Pad in the 903 Lip Area and south of the old firing range road and east the firing range. The 100-year simulation estimates of Pu-239/240 movement in the 903 Lip Area range from 4,000 pCi/m^2/yr to more than 25,000 pCi/m^2/yr (400 to 2,500 pCi/ft^2/yr); from 500 pCi/m^2/yr to 10,000 pCi/m^2/yr (50 to 1,000 pCi/ft^2/yr) to the south of the old firing range road; and up to 5,000 pCi/m^2/yr (500 pCi/ft^2/yr) east of the firing range. The predicted Am-241 mobility is lower than that for Pu-239/240, as expected. The small area of high mobility east of the firing range is not evident in the 100-year average Am-241 mobility map (Figure 28), but the area to the south of the firing range road is predicted to have a relatively high Am-241 mobility rate (up to 2,500 pCi/m^2/yr [250 pCi/ft^2/yr]).

No surface samples for roads in the SID watershed have been analyzed. Although it is suspected that the actinide activity in the road base material is lower than the activity in the surrounding soils, this has not been verified analytically (sampling will be conducted in FY01). Therefore, the actinide activity of the roads predicted by kriging is based on interpolation of sample results from soils located on either side of the roads. The actinide mobility predicted for the roads is an artifact of the kriged soil actinide concentration grid and estimates will be refined as data becomes available..

Estimates represented in Figure 29 and Figure 30 for the 100-year events in the SID watershed are relatively high, indicating a 1 percent chance of wide-spread Pu-239/240 and Am-241 movement on the hillslopes south and east of the 903 Pad Area during any year. Rates of movement estimated for the 100-year event are in the range of 25,000 pCi/m^2 (2,500 pCi/ft^2) and higher for Pu-239/240 in the 903 Pad Lip Area and 5,000 to 25,000 Pu-239/240 (500 to 2,500 pCi/ft^2) to the southwest, south, and east of the old firing range road. Am-241 mobility is predicted to vary from less than 250 to 5,000 pCi/m^2 (25 to 500 pCi/ft^2), with the largest portion between 1000 and 2500 pCi/m^2 (100 to 250 pCi/ft^2) the same areas. The mobility estimates and probability of occurrence are subject to the uncertainty inherent in the modeled estimates of erosion and actinide distributions.

7.3.2 Woman Creek Watershed Actinide Mobility

Figure 31 to Figure 38 are the actinide mobility maps for the Woman Creek watershed. The 100-year annual average actinide mobility maps are in Figure 31 to Figure 34. The maps indicate that estimated actinide movement is less than 10 pCi/m^2/year (1 pCi/ft^2/yr) for Pu-239/240 over a large portion of the watershed in the portion of the watershed west of Pond C-1.

Predicted mobility over small areas east of Pond C-1 to the Mower Diversion is up to 3,000 pCi/m^2/year (300 pCi/ft^2/yr) for Pu-239/240 and 500 pCi/m^2 /year (50 pCi/ft^2/yr) for Am-241. The road west of Pond C-2 (hillslope 49) shows a much higher actinide mobility rate but are suspected to be overestimated in the road materials by the kriged soil concentration grid.

There is increased mobility shown on the north side of the Woman Creek Diversion (north of Pond C-2). The diversion is a large area choked with cattails and other riparian vegetation that encourages sediment deposition and may limit actinide transport through the this portion of the channel. AME sediment surveys scheduled for FY01 will target this area to determine if it is an actinide sink.

7.3.3 Walnut Creek Actinide Mobility

A contiguous area of slightly elevated actinide mobility (less than 1,000 pCi/m^2/year [100 pCi/ft^2/yr] for Pu-239/240 and 100 pCi/m^2/yr [10 pCi/ft^2/yr] for Am-241) is shown around the A- and B-Series Ponds and along the south side of South Walnut and Walnut Creeks in Figure 39 to Figure 42. The soils on the north-facing hillslopes along South Walnut and Walnut Creeks dry slowly, are characterized by several seeps, and are relatively wet. This higher soil saturation, combined with the steep hillslopes, facilitates slightly more erosion than on the south-facing hillslopes. There are higher concentrations of Pu-239/240 and Am-241 in the soils of the north-facing hillslopes, especially along the top of the pediment, south of the B-Series Ponds. These factors make this area more susceptible to actinide movement relative to the rest of the Walnut Creek watershed. However, the actinide mobility is estimated to be low in comparison to the SID and Woman Creek.

The road along the B-Series ponds in South Walnut Creek appears to have a relatively high potential for actinide movement. However, as mentioned previously, the actinide activity of the roads predicted by the kriging is based on interpolation of sample results from soils located on either side of the roads. The B-Series pond road was dug up and refurbished during the East Trenches groundwater interceptor installation in 1999. Therefore, the activity on the road is likely to be much lower than predicted by the kriging and the actinide mobility predicted on the road is likely an artifact of the mapping methodology.

An area northwest of the East Gate in a small upland hollow that drains toward Indiana Street is predicted to be an area of relatively high actinide mobility (up to 3,000 pCi/m^2/year [300 pCi/ft^2/yr] for Pu-239/240). The hillslope is not tributary to Walnut Creek or any other stream that was investigated with the HEC-6T model and would not impact a water body.

Overall, actinide mobility in Walnut Creek is low, especially relative to the SID and Woman Creek watersheds, however, water-quality standards have been challenged with respect to Pu-239/240 and Am-241 in Walnut Creek, not in Woman Creek. The occurrences above 0.15 pCi/L were during low flow conditions, implicating contaminated bed sediment originating from the hillsides and/or actinides transported on colloidal material as possible sources.

7.4 Summary of Erosion Modeling Results

Seven erosion modeling tasks were completed for the current Site configuration, including the six storm events described in Section 6.0 plus the 100-year continuous simulation. Discussion of the model calibration and verification is presented in Appendix A. Significant findings of the erosion modeling effort include the following:

- WEPP results indicate that approximately 20 to 30 mm (0.79 to 1.2 in) of precipitation are needed to produce significant amounts of runoff and sediment yield on vegetated hillslopes (Figure 15);
- Modeled annual erosion rates for the three watersheds varied in the order; the SID at 0.384 T/ha (0.171 t/ac) > Walnut Creek with 0.324 T/ha (0.145 t/ac) > Woman Creek at 0.221 T/ha (0.099 t/ac).
- The 100-year simulations predict that hillslopes that include improved gravel roads produce one to ten times more sediment yield than undisturbed hillslopes and account for 29 percent to 49 percent of the total sediment yield for each watershed (Table 7 through Table 9). Revegetation of firebreak roads could reduce sediment yields from the road areas by up to 98 percent and total yields by up to 25 percent;
- The predicted 100-year average erosion rates for undisturbed hillslopes are similar to those for the 11-year, 11.5-hour and the 10-year, 6-hour return interval events (Table 7 through Table 9 and Table 12 through Table 14);
- Soil mobility maps were successfully created that identify areas of with high potential for erosion and transport of sediments to surface water;
- The predicted 100-year annual average movement of actinides ranges from less than 10 pCi/m^2/yr (1 pCi/ft^2/yr) to 25,000 pCi/m^2/yr (2,500 pCi/ft^2/yr) for Pu-239/240, and from less than 10 pCi/m^2/yr (1 pCi/ft^2/yr) to 5,000 pCi/m^2/yr (500 pCi/ft^2/yr) for Am-241 in the SID watershed. The area predicted to have greatest actinide mobility in the modeled watersheds is located in the 903 Lip Area and to the southwest and south of the old firing range road in the SID watershed (Figures 27 and 28);
- There is an area to the east of the old firing range which shows high potential for mobility of Pu-239/240and Am-241 for extreme events;
- Most of the Woman Creek watershed is estimated to have less than 10 pCi/m^2/yr of Pu-239/240 and Am-241 movement per year. In areas below the C-1 dam and to

north of the C-2 Pond in the Woman Creek watershed the 100-year annual average estimate of mobility is up to 3,000 pCi/m^2/yr (300 pCi/ ft^2/yr) of Pu-239/240 and up to 500 pCi/m^2/yr (50 pCi/ ft^2/yr) of Am-241;

- The areas of highest predicted actinide mobility in the Walnut Creek watershed are along the improved road along the B-Series ponds in the South Walnut Creek drainage (less than 1,000 pCi/m^2/yr for Pu-239/240 and 100 pCi/m^2/yr [10 pCi/ ft^2/yr] for Am-241) and in a small upland hollow just northwest of the East Gate (up to 500 pCi/m^2/yr [50 pCi/ ft^2/yr] of Am-241); and
- There is a continuous area extending along both the A-Series and B-Series Ponds, eastward on the south banks of South Walnut Creek and Walnut Creek with predicted actinide movement (100-year annual average) of about 10 to100 pCi/m^2/yr (1 to10 pCi/ ft^2/yr) of Pu-239/240 and 10 to 50 pCi/m^2/yr (1 to 5 pCi/ft^2/yr) of Am-241.

8.0 Sediment Transport Modeling Results

The HEC-6T model produces output that predicts the transport and deposition of sediments. The AME erosion modeling project has developed methods to use the HEC-6T output for estimating transport of Pu-239/240 and Am-241 that is associated with the suspended sediments. The model calculates actinide transport based only on the erosion of hillslope material, not from the erosion of sediment bed material.

Predicted sediment and runoff yields are well within an order of magnitude of measured data. Measured sediment yields were estimated using continuous discharge and total suspended solids concentrations from Site gaging stations (Figure A-3). The sediment yields predicted by HEC-6T were compared to the measured yields to evaluate the model's performance. A detailed evaluation of the HEC-6T model calibration and comparisons of measured and predicted values for flow and total suspended solids are in Appendix C. The results of the HEC-6T modeling for each watershed are summarized in Table 13. These data compare well with measured data from the Loading Analysis Report (RMRS, 1998b) results, Site monitoring data, and previously completed hydrologic modeling results in the Drainage and Flood Control Master Plan.

Figures C8 to C10 show examples of the simulated WEPP and HEC-6T sediment yields for selected events for all three watersheds. The models predict very little deposition in the western, high-gradient stream channels. Deposition is predicted in the detention ponds and low-gradient channels in the eastern portion of the Site. Plots of the predicted WEPP sediment delivery and HEC-6T sediment transport are provided for every design storm for every watershed in Appendix C.

The simulated sediment yields can be used to design engineered controls for erosion abatement and sediment containment. Results from the simulation will be used to help determine the useful life of the Site detention ponds; evaluate the costs for maintaining (i.e., cleaning out) the ponds, design of berms, ponds, or other sediment control structures; and assess downstream impacts on the Big Dry Creek watershed. The simulation results will also aid in planning for future operations of the detention ponds and the final remedial design for land and drainage configuration.

8.1 Simplifying Assumptions and Model Impacts

Computer models simplify the actual processes occurring in nature, and many simplifying assumptions were made in the development and use of the HEC-6T model. Several of the assumptions could have an impact on the predicted sediment transport and Pu-239/240 and Am-241 concentration results. Examples of major simplifying assumptions and their impact on the models are outlined below (see Appendix D for a discussion of model uncertainties).

The Woman Creek and Walnut Creek watersheds extend further to the west of the Site and are larger than covered in the models. During events the size of a 2-year storm or greater, water draining from west of the Site enters the watersheds increasing flow and sediment transport.

No channel erosion is included in the HEC-6T models for the Site. This assumption was deliberately chosen to enable tracking of the hillslope sediment and associated Pu-239/240 and Am-241 through the model segments. The Site channels are generally well armored with cobbles and gravel, but the banks contain erodible clay, silt, and sand material. The channels are straighter on the western side of the Site with increasing meanders to the east (Figure 1). Therefore, channel widening (not deepening) and meander erosion is expected to dominate during extreme events. The channels are modeled as straight, with no energy loss at the meanders; this inhibits sediment deposition in the models and keeps more sediment suspended in the flow. Therefore, the simplifying assumption of no meanders or energy loss due to meanders is conservative and may compensate for the lack of meander erosion.

Hillslope sloughing in the SID watershed has reduced the capacity of the SID channel, especially near Building 881 where the Operable Unit Number 1 French Drain construction has impacted the channel capacity (EG&G, 1992a). During the May 17, 1995, event, the SID overflowed in this area. The SID HEC-6T model does not account for this condition. The reduced capacity of the channel and overflow during large events could reduce sediment yields to Pond C-2 and could channel sediments from the 881 hillslope and to the west into Woman Creek.

Mower Ditch does not have the capacity to carry all of the flow predicted for the extreme events, especially the 100-year event. Shallow flooding between the Mower Ditch and Woman Creek would be expected to occur on hillslopes 39 and 43. This condition could increase sediment and Pu-239/240 and Am-241 mobility on these hillslopes. Sediment and actinide yields could increase for Woman Creek at Indiana Street (GS01) and decrease for Mower Ditch at Indiana Street (GS02).

The Woman Creek model predicts a substantial amount of flow, sediment, and Pu-239/240 and Am-241 yield to Woman Creek from the Smart Ditch overflow (Segment 2 in the HEC-6T model) for large events. Hillslope 34 is a large, steep hillslope containing an improved road that generates large amounts of sediment and runoff yield for extreme events in the WEPP model. Soil samples on or near hillslope 34 have elevated Pu-239/240 and Am-241 activity, which is reflected on the kriged distribution maps (Appendix B). The road has not been sampled. The results for Smart Ditch are suspected to be artifacts of the lack of samples from the road; of smoothing of Pu-239/240 and Am-241 concentration in the kriging process, and of the WEPP model which does not account for roadside ditches and other small scale features that limit sediment yields to the streams. AME stream-sediment sampling planned for FY01 should help to quantify the actual Pu-239/240 and Am-241 contributions from the Smart Ditch overflow channel.

No Name Gulch in the Walnut Creek watershed is predicted to contribute high sediment yields to Walnut Creek in the HEC-6T models for high flow events, and Pu-239/240 and Am-241 concentrations are also predicted to be elevated. Monitoring at gaging station GS33 does not support such large yields, although sample results are for much smaller events, and Pu-239/240 and Am-241 concentrations are near detection limits in the GS33 water samples (Appendix A). The watershed is largely undisturbed with the exception of improved roads high atop the hillslopes draining to the gulch and gullying on tributaries in the western portion of the drainage.

Model predictions of sediment deposition in the central and eastern reaches of the channel are supported by field observations. Hillslope 29 contributes a relatively high quantity of sediment to the No Name Gulch channel just before it enters a shallow stock pond in which much of the eroded material is predicted to settle out. A large amount of sediment deposition is also predicted as the channel gradient flattens near the mouth of the gulch.

In summary, concentrations predicted for No Name Gulch are suspected to be conservative artifacts of the modeling assumptions and the kriging analysis, although the overall behavior of the HEC-6T model for No Name Gulch appears to be consistent with field observations. The kriging analysis predicts levels above 1 pCi/g in the drainage, but sampling data collected by the AME indicates concentrations are generally well below 0.1 pCi/g. This alone accounts of an overestimation by a factor of 10 or more for Pu-239/240 concentrations in surface water for the drainage. Sediment sampling indicates low activity in the sediments at the east end of the drainage (Figure C-5 and Figure C-6). The generally accurate predictive quality of the models indicates that No Name Gulch is a source of sediments during large events. This is supported by the observation of intense gullying on hillslopes in the upper reaches below the Landfill Pond.

8.2 Summary of HEC-6T Model Results

The HEC-6T models for each watershed (Mower Ditch, SID, Woman Creek, and Walnut Creek) all behave in a consistent and realistic manner with the following characteristics (this section is discussed in detail in Appendix C). Model predictions include the following:

- Sediment deposition decreases with increasing discharge (peak flow) (Figure C-7);
- Sediment transport is more efficient in steep channels, and sediment deposition increases in flatter ones (Figures C-8 and C-9);
- The detention ponds act as sediment sinks, with sediment deposition occurring even though the ponds are modeled as full, with flow routed over the emergency spillways (Figures C-8 to C-10);
- Cumulative WEPP sediment yields (in a downstream direction) trend with the HEC-6T routed sediment yields (Figures C-8 and C-9);
- Sediment deposition increases in a west to east (downstream) direction as the natural channel gradients decrease (Figures C-8 to C-10);
- Average suspended sediment concentrations increase with increasing peak discharge (Figure C-11 and C-12);
- Sand and large silt-sized particles are deposited in the models. Clay and small silt-sized particles are efficiently transported through each watershed;
- Simulated sediment yields and concentrations compare favorably with the limited measured data from Site stream gaging stations, the Loading Analysis, and the Drainage and Flood Control Master Plan (Table 10);
- The models produce reasonable estimates of stream-flow and sediment yields (Figures C-13 and C-14); and

- The models produce reasonable estimated stream plutonium (Pu-239/240) and americium (Am-241) concentrations when the HEC-6T results are incorporated into the Pu-239/240 and Am-241 transport models as discussed in Section 9.

The models predict runoff, sediment yields, and TSS concentrations that are reasonable. The results compare favorably with measured or previously modeled values (Appendix C). The runoff yields and peak discharges appear to be larger than expected. However, since 1991, data collected on May 17, 1995 is the only time when measurements were made and samples were collected during an extreme storm event. Data for this event are of poor quality because the event destroyed many of the gaging stations in the Site monitoring network. Additional samples of actinide concentrations and TSS collected during large storm events would be very beneficial for calibration of the models at high flows.

A comparison of the predicted and measured sediment yield data for each watershed in Figures C-11 through C-14 demonstrates that the Walnut Creek simulation results generally do not fit the trends of the monitoring data as well as the results for other watersheds. However, the results for the 2-year and 10-year, 6-hour events fit very well. The apparent greater uncertainty for the Walnut Creek watershed may be due to the complexity of the watershed with its nine detention facilities and the detention pond operations that impact the measured watershed yields in ways that are not accounted for in the model.

The Woman Creek and SID simulation results appear representative of their respective watershed conditions. The limited monitoring data compare reasonably with the simulation results for these two watersheds (Figures C-11 to C-14). Results for Mower Ditch are mixed, but there are very few data for gaging station GS02, located on the Mower Ditch at Indiana Street (Figure C-12). Other limitations were discussed previously.

The estimated average Pu-239/240 and Am-241 concentrations for each design storm were derived from the combined results of WEPP, kriging analysis of the Pu-239/240 and Am-241 distributions in Site soils, and HEC-6T. A detailed discussion of the techniques used to calculate the estimated Pu-239/240 and Am-241 concentrations is provided in Appendix B. The results of this effort—the estimated Pu-239/240 and Am-241 concentrations along each drainage for the six design storms—support the conclusion that WEPP and HEC-6T results are reasonable.

9.0 Estimation of Pu-239/240 and Am-241 Transport

The results of the HEC-6T modeling were compared with the monitoring data and were determined to be acceptable for incorporation into spreadsheet models programmed to compute average Pu-239/240 and Am-241 concentrations in surface water for every HEC-6T cross-section in every watershed. The spreadsheet models are hereafter referred to as the Pu-239/240 and Am-241 transport models.

A detailed description of the models and the development process is given in Appendix B. Estimation of Pu-239/240 and Am-241 concentrations and yields in the main channels of each watershed was accomplished by assigning Pu-239/240 and Am-241 concentrations to the tributary sediments based on the kriging analysis and then calculating concentrations using the HEC-6T output. The HEC-6T output includes the following data for each main channel cross-section:

- Total sediment yield (tons);
- Total water runoff yield (ac ft); and
- Particle -size distribution of sediment.

The concentrations and particle size distributions of the Pu-239/240 and Am-241 in the sediments contributed by each WEPP hillslope were calculated. A GIS application was developed to merge the spatial analysis (kriged grid) of Pu-239/240 and Am-241 distributions in the surface soils with the WEPP erosion data (erosion grid). The combination of these two spatial distributions was used to calculate the Pu-239/240 and Am-241 concentrations of the sediment delivered to the channels. The sediments and their associated Pu-239/240 and Am-241 concentrations were combined with the HEC-6T output to estimate Pu-239/240 and Am-241 concentrations in the surface water for each cross-section in the HEC-6T mode (Appendix B)

The Pu-239/240 and Am-241 transport models incorporate the water-stable aggregate-size distributions of Pu-239/240 and Am-241 determined by Colorado School of Mines (CSM) for the AME in order to calculate enrichment factors for Pu-239/240 and Am-241 in the sediments from the hillslopes (see Appendix B). The Pu-239/240 and Am-241 concentrations of the hillslope sediment are then assigned to the HEC-6T particles by size. A large portion of the Pu-239/240 and Am-241 associated with large (i.e., sand-sized) particles are deposited to the streambed in the Pu-239/240 and Am-241 transport models. Conversely, the Pu-239/240 and Am-241 on the clay and silt-sized particles tend to stay in suspension and are transported downstream. A discussion of the water-stable aggregate-size distribution of Pu-239/240 and Am-241 and how they are used in the transport models is provided in Appendix B.

The Pu-239/240 and Am-241 transport models are primarily used to determine the following:

- Storm events and stream segments with predicted Pu-239/240 and Am-241 concentrations above the current Colorado Water Quality Control Commission (CWQCC) standards of 0.15 pCi/L for Pu-239/240 and Am-241 for selected single events;
- The hydrologic risk (probability) that the current 0.15 pCi/L level, or other chosen concentration level, will be exceeded;
- Stream segments where Pu-239/240 and Am-241 deposition (i.e., sinks) occurs;
- Potential Pu-239/240 and Am-241 yields off-Site to the Big Dry Creek watershed; and
- Impacts on surface water quality when levels of actinides in the surface soil are reduced.

9.1 Model Structure and Implications

For the SID and Walnut Creek watersheds, surface water monitoring data from Site stream gaging stations was used to simulate Pu-239/240 and Am-241 loading into the streams from the IA. Therefore, the Pu-239/240 and Am-241 concentrations in the SID and Walnut Creek are affected by IA inputs as well as the hillslope erosion modeled in WEPP.

In the HEC-6T and Pu-239/240 and Am-241 transport models, Pu-239/240 and Am-241 concentrations from gaging station GS10 were used for the South Walnut Creek. Data from stations SW093 and SW091 were used for IA inputs to North Walnut Creek. Data from station SW998 was used as input for the McKay Ditch. Data for IA inflows to the SID were obtained for gaging stations GS21, GS22, GS24, and GS25.

IA runoff to the SID normally does not have high concentrations of Pu-239/240 and Am-241, unlike concentrations frequently observed at GS10, SW091, and SW998 in Walnut Creek (Appendix A). Therefore, water-quality is impacted by the IA in the Walnut Creek Pu-239/240 and Am-241 transport models but not in the SID. IA sources supply most of the runoff to the SID, providing the driving force that transports the Pu-239/240 and Am-241 in the SID channel, but the Pu-239/240 and Am-241 load is derived from hillslope erosion in the 903 Pad Area. Diverting IA storm flow from the SID could significantly reduce flow in the SID and decrease transport of actinide contaminated sediments to Pond C-2.

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9.2 Discussion of Model Results

The results of the Pu-239/240 and Am-241 transport models are summarized in Table 14 and Figure 44 through Figure 61. Pu-239/240 and Am-241 concentrations in runoff samples collected at Site gaging stations are summarized in Table E-5 in Appendix E. The range of Pu-239/240 and Am-241 concentrations in the monitoring data were compared to the predicted concentrations for the 35-mm and May 17, 1995 storms, because these events, or at least similar events, have been observed and measured at the Site. The measured and predicted Pu-239/240 and Am-241 concentrations were plotted against measured and predicted runoff values to determine if a visible trend exists between the two data sets. Although no statistical testing was done to evaluate significant differences between the measured and predicted values, the predicted values appear to be reasonable extensions of the measured data set (Figure 43).

Pu-239/240 and Am-241 activity changes with downstream distance along selected reaches of the Site watersheds Figure 44through Figure 61). Under RFCA, the Site must achieve Pu-239/240 and Am-241 action levels and standards at POE and POC locations, respectively (See Section 1.2 for a description of applicable RFCA protocols). Compliance is based on a time-weighted, moving average concentration. The modeling results for the selected hydrologic events indicate that predicted surface-water concentrations of Pu-239/240 and Am-241 will be greater than 0.15 pCi/L in some areas of all the streams during extreme hydrologic events. The action levels / standards are based on time-weighted moving average concentrations of all flows over a specified period of time (e.g., a month or more), not just storm events. Therefore, a storm event could cause the measured Pu-239/240 and Am-241 concentrations to exceed 0.15 pCi/L for the storm, but that does not necessarily mean that the average of the measured concentration(s) over the duration of the averaging period will exceed the action level or standard.

This emphasizes the importance of the separate question of the acceptable hydrologic risk (probability) of the occurrence of action level / standard exceedance. For example, if the action level / standard is exceeded only for the 10-year event (and larger) then the probability of an exceedance is less than 0.1 (10 percent chance) in any year due to the time-weighted averaging calculation. If the standard is exceeded for a 2-year event, then the probability of an exceedance is less than 0.5 (50 percent chance) in any year. Determination of an appropriate hydrologic risk for surface water actinide concentrations at points of compliance or points of evaluation above an standard / action level is a key factor in evaluating remediation and management strategies or runoff and erosion control. An acceptable hydrologic risk must be determined in order to make full use of the Pu-239/240 and Am-241 transport models as decision tools.

Table 14 summarizes Pu-239/240 and Am-241 transport model predictions of stream segments with concentrations above 0.15 pCi/L and the probability of occurrence in any year. Selected results follow.

Areas predicted to have high probability of occurrence:

- The SID in the eastern reach due south of the 903 Pad Area to Pond C-2 (SW027);
- Woman Creek from the confluence with Antelope Springs Gulch to Pond C-1 and between the Woman Creek/Pond C-2 Diversion and Indiana Street (GS01);
- The Smart Ditch overflow to Woman Creek;
- The Mower Ditch from about 300 yards downstream from the Mower Diversion to Indiana Street (GS02);
- North Walnut Creek from the IA inflow at SW093 to Pond A-4 (GS12), 50 percent probability of occurrence; and
- No Name Gulch from about 500 yards downstream from the Landfill Pond dam to just below the old stock pond dam.

Areas predicted to have low probability of occurrence:

- South Walnut Creek from the IA (GS10) to the confluence with North Walnut Creek; and
- Walnut Creek from the confluence with No Name Gulch to Indiana Street (GS03).

Table 14 summarizes the stream reaches and associated storm return intervals the Pu-239/240 and Am-241 transport models predict will cause surface water concentrations above 0.15 pCi/L. The probabilities presented in Table 14 do not account for the combined uncertainty of the WEPP and HEC-6T models and the integral components of the Pu-239/240 and Am-241 transport model. Another important source of uncertainty is that the detention ponds are modeled as full, with flow routing over the emergency spillways. Most of the predicted concentration above 0.15 pCi/L for Walnut Creek, downstream from the detention ponds, may not occur if the ponds are not full and can contain the stormwater runoff. This scenario may be modeled in the future.

Few measured stormwater runoff data are available for Mower Ditch at Indiana Street (GS02) and Woman Creek at Indiana Street (GS01), but more data are available for the SID (SW027) and Walnut Creek at Indiana Street (GS03) (Table E-5). For small events, simulation results for Walnut Creek at GS03 (Table 13) appear to be within the range of the observed data. For the SID the simulated actinide concentrations appear to be within the range of the observed data for the 35-mm event, but they are overestimated by an order of magnitude (or more) for the other storms. For Mower Ditch, simulated actinide concentrations appear to vary from within the range of the observed data to overestimated by more than an order of magnitude. For Woman Creek, the simulated actinide concentrations vary from within the range of observed data to overestimation by two orders of magnitude. Overall, comparison of the simulated Pu-239/240 and Am-241 concentrations (Table 13) with the measured data (Table E-5) reveals that the models provide an indication of the types of events and conditions that are expected to impact surface-water quality. Improved prediction of actinide concentrations may be achieved through a better understanding of the particle-size distribution and actinide enrichment in delivered sediments. It may also be improved by better modeling of the ponds and information from sampling actinide concentration in the roads.

9.3 Implications for Surface Soil Contamination Remediation

One of the objectives of the Pu-239/240 and Am-241 transport models is to aid in determining surface soil cleanup levels of Pu-239/240 and Am-241 that will be protective of surface-water quality. A spreadsheet module that links to the surface-water actinide concentration model (described in Appendix B, Section B.8) was developed for the SID drainage basin to support modeling a range of remediation scenarios and the resulting impacts on surface-water quality. This module allows for rapid evaluation of the effects on surface water quality caused by changes in actinide levels in the soil in the SID drainage basin. The soil actinide concentration adjustment model determines Pu-239/240 and Am-241 concentrations of erosion sediments leaving the hillslopes for specified storm events after remediation of contaminated soils to a user-specified level. A description of the development of the soil actinide concentration adjustment model is provided in Appendix B, Section B.9.

The soil actinide concentration adjustment model assumes the existing land surface topography, vegetative cover, and soil type remain in place, and Pu-239/240 and Am-241 surface soil concentrations as generated by the GIS model. It applies to the remediated areas after revegetation is complete. The potential effects of the remediation operations will be modeled using WEPP in FY01. Functions in the module allow the user to specify the maximum allowable Pu-239/240 soil activity level (in units of pCi/g) for any of the 1 percent intervals within any OFE in the SID basin. The Am-241 levels remaining on the hillslopes is calculated from the specified Pu239/240 level. Any intervals that are equal to or exceed the specified Pu-239/240 level are automatically changed or "cleaned up" to the new Pu-239/240 and Am-241soil activity levels specified by the user. The output from the soil actinide concentration adjustment model was input to the Pu-239/240 and Am-241 transport model to simulate the water quality resulting from the remediation scenario.

Results of the soil actinide concentration adjustment model are currently available for the SID watershed. Similar modeling, to assess the impacts on water quality when surface soil actinide levels are modified, has not been done in other watersheds, but could be developed and utilized as a tool in the future when developing the Site's final remedial design. Remediation of the very low levels of actinide soil contamination in the Woman Creek and Walnut Creek watersheds was not addressed in this study. Woman Creek and Walnut Creek modeling results were limited strictly to the existing conditions of soil actinide levels.

The soil actinide concentration adjustment model results for 10-year and 100-year storms are shown for the SID in Figure 62 through Figure 66. The results indicate that both of the events modeled cause surface water concentrations above the current surface water Action Level of 0.15 pCi/L in at least some portion of the SID, even if all soils in the area above 10 pCi/g Pu-239/240 are removed. Model estimates indicate remediation of Pu-239/240 soil contamination above 10 pCi/g will result in surface water of acceptable quality at the mouth of the SID (SW027) for most storm events.

As noted in Section 8.2, surface water monitoring data collected during an extreme storm event is limited to May 17, 1995 (11-year, 11.5-hour event) and these data are of poor quality because of damage caused by the event to the gaging stations in the Site monitoring network. Additional samples of actinide concentrations and TSS collected during large storm events would be very beneficial for calibration of the models at high flows. Better model calibration would improve the certainty associated with predicting water quality impacts as a result of changes made to actinide levels in the soil.

The soil actinide concentration adjustment model demonstrates that low, diffuse sources of Pu-239/240 and Am-241will contribute to surface water concentrations. To reach final regulatory closure, the Site must be proven to be protective of human and ecological health, including surface water. Work to date indicates a combination of measures will need to be implemented to achieve the desired goals for limiting Pu-239/240 and Am-241 transport via the erosion and sediment transport pathway. These measures may include soil remediation (i.e., removal), erosion and runoff controls, hydrologic modifications, land uses, and other management alternatives. Information presented in this report, future refinements and planned applications of the models will aid in determining the route to final Site regulatory closure.

10.0 Uncertainties

10.1 Description of Uncertainty Types

Computer models rely on an underlying conceptual model of a physical process or set of processes, mathematical algorithms that attempt to replicate these processes, and input data or measurements. Each of these items contains a degree of uncertainty, which, to varying degrees, affect the overall quality and uncertainty of the model estimates.

Input values to the model, such as precipitation, temperature, and watershed characteristics subject to statistical sampling, are random variables. Therefore, results output from the model are random variables and, as such, are subject to various levels of uncertainty. In as much as the model quantifies erosion and deposition, there must be some confidence that the model is able to simulate accurately those same processes that have resulted in the present conditions at the Site. To assess the overall quality of the model, it is important to understand the nature of the uncertainties, their relative or quantified magnitudes, their impacts on the model, and how the impacts are mitigated and minimized during the modeling processes. This section provides a brief description of the uncertainties associated with this modeling project. Further detail on the uncertainty analysis is provided in Appendix D.

Model output uncertainty can be attributed to three general sources: 1) structural uncertainty; 2) input uncertainty; and 3) parameter uncertainty. These three categories of uncertainty are briefly discussed below:

- Structural uncertainty relates to the degree to which the model accurately and completely represents the physical system under analysis. Physical systems are typically highly complex and often contain components that are not completely understood or measurable. As such, any model of the system must make simplifying assumptions to reduce the level of complexity, account for knowledge gaps, and offer a solution that is feasible given available technology while maintaining structural integrity.
- Input uncertainty relates to the variability inherent in natural phenomena and the ability to collect data that accurately represent the true characteristics of the associated parameters. Two major types of uncertainty exist with regard to data input errors. The first is *measurement error*, such as data derived from the measurement of rainfall for an event, flow volume in channels, or sediment yield from a hillslope. The second category of input uncertainty is the *spatial and temporal variability* associated with these data. Parameters such as vegetative cover, soil actinide concentrations, average rainfall, and other parameters are subject to spatial and/or temporal variation. Whereas these parameters are known to vary, they are typically

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represented by a parametric average in the modeling process. Use of an average value represents a loss of information that introduces a degree of uncertainty to the model output. The impacts of averaging may vary from negligible to significant. Key data input uncertainties are summarized in Appendix D.

- Parameter uncertainty is related to internal model parameters that are fixed and that may or may not be available for adjustment by the user. For example, the WEPP model calculates the midpoints of particles size distributions through an internal program routine that is not adjustable by the user. Other examples are the climate generation model, where the Log Pearson III approach is used by default, certain contouring algorithms where all internal parameters are fixed, and certain types of geostatistical analyses involving logarithmic transformations. Model parameter uncertainties are summarized in Appendix D.

For decision making in this modeling project, the general rule was to exercise judgment that would be expected to produce conservative results from the model, i.e. would tend to raise the volumes of erosion, sediment, and radionuclide activity in surface waters, while achieving reasonable calibration to Site data. This approach was considered to be more protective of human health and the environment. Table D-10 in Appendix D lists specific decisions that were made that have contributed to an added level of conservatism in the model. The result of overcompensation with respect to conservatism, however, is a model that will not reflect reality for most situations. For example, if parameters are used for which one can expect only a 10 percent chance of occurrence (90 percent confidence) for each of three independent variables, the chance that this outcome will actually occur is only 1 in 1,000. The outcome of this approach can be a model that produces unrealistically conservative results, beyond even a "worst case" scenario. Tables D-11 and D-12 in Appendix D demonstrate how conservative overcompensation can affect the reliability of the model.

10.2 Model Calibration and Uncertainty Analysis

The process of model calibration plays a crucial role in checking the compounding of uncertainty as it provides a system of checks and balances on the variability and impact of the input parameters. Even though some of the data for the calibration are subject to uncertainty, the model must perform to provide results that can be confirmed by measured data in which a good deal of reliability exists (Site surface water flow data, Site suspended sediment data, etc).

Calibration is subject to a lack of uniqueness of solutions. Many combinations of reasonable (or unreasonable) parameters may yield the same result. Combinations of extreme, yet negating, parameters can yield a "good" calibration if good professional judgment is not used. The sensitivity analyses performed on the model provided insights for the calibration

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process and aided in parameter selection. Parameters were varied so that a perspective was obtained on the calibration. Discussions of calibration and sensitivity for the WEPP and HEC-6T models are provided in Appendices A and C, respectively.

10.3 Summary of Model Uncertainty

Due to the complex nature of the individual primary models and submodels along with the complex interaction between the models, it is not possible to derive a single measure of the uncertainty on the overall model predictions, and thus, the impact on surface water. Model inputs and outputs are random variables. Without a stochastic analysis, the range of uncertainty of expected model output values can not be calculated precisely.

Comparisons of model results with measured data, as detailed in Appendices A and C, indicates that the model's predictions of erosion, sediment transport, and actinide concentrations in surface water range from slight underestimation to overestimation by a factor of about 5. The available monitoring data for determination of this factor are limited, thereby introducing additional uncertainty. Most of the monitoring data are for typical low flows that are much smaller than the modeled events. The May 17, 1995 flood is the only extreme event for which any monitoring data exist, and those data are incomplete and estimated because the flood waters damaged many monitoring stations.

Tysdal (1999) completed an independent determination of the erosion rates in the eastern SID watershed using the WEPP model. Tysdal (2000) obtained an average erosion rate of 0.672 T/ha (0.300 t/ac) for the SID drainage compared to the 0.384 T/ha (0.171 t/ac) estimated by the current model. Tysdale used the SID sediment core data to calibrate the WEPP model instead of the rain simulator data, which was not available at the time of her study. The SID sediment core data are of uncertain quality (Appendix C). Also, design drawings for the SID show that six inches of seeded topsoil were added to the channel at construction, which casts doubt on the cores being representative of hillslope erosion. Due to the high standard deviation of the erosion estimates (discussed in Section 7.1) the Tysdale estimate is well with in the predicted range of yearly values (Figure 14). Tysdal's estimated erosion rate is considered to be an upper bound on the range of average erosion rates for the SID watershed.

No statistical tests were made between the measured and predicted erosion rates, runoff yields, or sediment yields to evaluate the uncertainty in the results. The material in Appendices A and C provide comparisons of measured and predicted values that give a qualitative perspective of the uncertainty associated with the model results.

11.0 Summary, Conclusions, and Future Work

The work to date presented in this report provides tools for making informed management decisions regarding contaminated soil remediation and management at the Site. The tools developed for this study may be applied to other soil contamination problems where the contamination is insoluble and has a strong affinity for sorption to a solid phase (e.g., sediment).

Uncertainties in the models including assumptions, inputs, and outputs have been identified, qualified, and quantified in Appendix D. Many of the uncertainties have been accounted for during the sensitivity analysis and model calibration steps of the modeling process. In addition, much of the compounding of conservatism has been taken into account and adjusted appropriately. By analyzing the results from the work to date, it is estimated that the model predictions of sediment and actinide concentrations in surface water vary from slight underestimation to over-estimation by a factor of 5.

The following conclusions are derived from the work to date presented in this report:

- The 100-year annual average erosion rate for the Site watersheds is estimated to range in the order; the SID at 0.384 T/ha (0.171 t/ac) > Walnut Creek with 0.324 T/ha (0.145 t/ac) > Woman Creek at 0.221 T/ha (0.099 t/ac), resulting from about 4 percent of the annual precipitation leaving the Site as runoff. The erosion rate translates into an estimated annual erosion depth of 0.02 to 0.04mm when averaged across the entire Site.
- The predicted erosion combined with the spatial distribution of Pu-239/240 and Am-241 contamination in the Site soils has been mapped in Pu-239/240 and Am-241 mobility maps that indicate where Pu-239/240 and Am-241 are relatively mobile (Figure 27 through Figure 42). These areas are 1) the 903 Pad Area; 2) southwest, south, and a small area east of the old firing range road; 3) the Woman Creek watershed between the Pond C-1 dam and the Mower Diversion, and 4) the A- and B-series Ponds, South Walnut Creek, and the north-facing hillslopes adjacent to South Walnut and Walnut Creeks.
- Simulated Pu-239/240 and Am-241 concentrations in Site streams provide a means for evaluating areas where soil contamination levels may impact surface-water quality (Figure 44 through Figure 61). These areas are the following: 1) the SID watershed from the 903 Pad Area east to Pond C-2; 2) the Woman Creek watershed from Antelope Springs to the Mower Ditch and from the Smart Ditch Overflow to Indiana Street; 3) the Mower Ditch; 4) North and South Walnut Creeks and the A- and B-Series ponds from the Industrial Area to the confluence with No Name Gulch; and 5) No Name Gulch from the Landfill Pond dam to about 300 yards upstream from the confluence with Walnut Creek.

- Figure 66 and Figure 67 present a summary of the predict erosion rates for hillslopes in the SID, sediment yields at SW027, and PU-239/240 and Am 241 concentrations at SW027 as a function of hydrologic probability of occurrence calculated from the results of the single storm simulations. This indicates that the 100-year average erosion rate is likely to occur only once every ten years (10 percent chance of occurrence). However, at existing surface soil actinide activities, it is likely that the current surface water action levels will be challenged in any given year.
- Results from the soil actinide concentration adjustment model for 10-year and 100-year storm simulations indicate that both of the events cause surface water concentrations above 0.15 pCi/L in at least some portion of the SID, even if all soils in the area above 10 pCi/g Pu-239/240 are removed.
- The Site will need to evaluate a combination of soil remediation (i.e., removal), erosion and runoff controls, hydrologic modifications, land uses, and other management alternatives to achieve the desired goals of limiting Pu-239/240 and Am-241 transport via the erosion and sediment transport pathway.
- Results of this modeling effort indicate that overland flow and soil erosion are less likely causes of the elevated concentrations of Pu-239/240 and Am-241 in Walnut Creek. Pond operation, colloidal Pu-239/240 and Am-241, or contaminated bottom sediments are the most likely causes.

The AME erosion and sediment modeling project developed the following products: 1) a comprehensive geostatistical analysis of the spatial distribution of Pu-239/240 and Am-241 contamination in Site soils; 2) a detailed soil erosion model for the Site to estimate sediment yields to Site drainages in both the short- and long-term; 3) soil mobility (erosion) maps; 4) Pu-239/240 and Am-241 mobility maps; 5) estimated sediment transport and deposition patterns in the drainages; and 6) surface-water Pu-239/240 and Am-241 concentrations in surface water for storm events with specific return intervals (probabilities). The models, methods and data resulting from this study are tools that are available to guide Site final remedial design, management, land configuration designs, and regulatory closure. They may also be very useful in guiding pre-, current, and post-closure monitoring.

Additional data will increase the power of the models as tools. Site-specific studies to determine how the particle-size distribution of sediment entrained in overland flow relates to the particle-size distribution of the parent soil would be useful. Further investigation of how the particle-size distribution of Pu-239/240 and Am-241 in the entrained sediment relates to that of the parent soil material would bridge an important gap in the current model uncertainty. A more extensive sediment yield data set that includes flows and suspended sediment samples for extreme events would also strengthen the verification of the model calibration. Soil samples from roads and sediment samples from the stream beds would provide better estimation of Pu-

239/240 and Am-241 mobility in overland flow and more detailed estimation of the actinide concentrations in the streams.

The importance of this study and overland transport of Pu-239,240 and Am-241 from water erosion of Site soils was confirmed during the May 17, 1995 flood. A team of researchers lead by Dr. M. Iggy Litaor, collected overland runoff samples in the 903 Lip area. The samples were collected in a somewhat non-reproducible fashion by hand bailing overland flow in two swales that extend from the old shooting range down to the SID. Despite the questionable quality of the data, they indicate that overland transport of Pu-239/240 and Am-241 from soil erosion processes is important and can affect surface-water quality (RMRS, 1995). These data were collected for an extreme event, and as such they are unique.

Modeling of future scenarios for extreme environmental conditions, range fires, various land surface configurations, hydrologic modifications, remediation scenarios and potential land uses are planned for FY-01 (Kaiser-Hill, 2000a). These scenarios will provide additional tools and increased understanding of physical transport processes to assist with development of the Site's final remedial design.

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TABLES

Table 1. Definitions of Frequently Used Erosion Terms[1]

Term	Definition
Deposition	Settling of entrained soil particles.
Detachment	Freeing of soil particles from the bulk soil by raindrop impact and flowing water shear stress.
Interrill	Areas between rills characterized by diffuse, sheet flow.
Interrill erosion	Detachment (see above) of soil particles and transport by sheet flow.
Overland flow	Movement of runoff across the soil surface;, includes sheet flow and rill flow.
Rill	Area supporting concentrated flow; a micro-channel.
Rill erosion	Detachment and transport of soil particles by rill flow (see below).
Rill flow	Concentrated or channelized (in rills) flow of runoff.
Runoff	Precipitation in excess of a soils infiltration and surface storage capacity; moving across the soil surface.
Sediment discharge	Movement of a sediment mass past a point; dependent on the velocity of flowing water.
Sediment transport	Entrainment and movement of soil particles with flowing water.
Sediment yield	Net result of detachment, transport, and deposition, resulting in sediment moving past a point of interest expressed per unit area and time period.
Sheet flow	Non-channelized flow of runoff across interrill areas.
Soil loss	Amount of soil per unit area and time leaving an area without significant deposition.

[1]Adapted from Weltz et al. 1998.

Table 2. WEPP Model Data Input Requirements

Input File[1]	Data Needs	Source
Climate file	Meteorology data, precipitation, wind, temperature, and dew point	ARS Fort Collins Data and CLIGEN 100 -year simulation supplemented with site meteorological data
Slope file	Overland flow elements[2] (OFE), hillslope length, width, and slope	2-foot contour mapping; soils and vegetation GIS coverage in ArcInfo
Soil file (one for each OFE)	Soil type, textures, OM, hydraulic conductivity, CEC, albedo, and number and depth of soil layers	Site RFI investigations,AME research, GIS data,previous OU2 Research, and SCS soil surveys
Plant management files (information input for each OFE)	Initial soil and plant conditions, plant types and growth parameters, cover characteristics, and management practices	Site ecological monitoring data, GIS coverages from aerial surveys, WEPP User's Guide, and journal articles

1. All of the WEPP input data files for each watershed hillslope are contained on a CD-ROM (in pocket). The data files are arranged in Microsoft® Explorer™ folders for easy use in a standard WEPP Version 99.502 model.
2. Overland Flow Elements are regions of homogeneous soils, cropping, and management on a hillslope. Each hillslope may have up to 10 OFEs.
3. Acronym Definitions:

OM	=	Organic Matter
CEC	=	Cation Exchange Capacity
GIS	=	Geographic Information Systems
RFI	=	RCRA Facility Investigation
AME	=	Actinide Migration Evaluation
OU	=	Operable Unit
SCS	=	Soil Conservation Service

Table 3. Hillslope and Overland Flow Element Dimensions, Habitat Type, and Soil Type for the Woman Creek Watershed WEPP Model

Hillslope Number	OFE Number	Habitat Type	Surface Soil Type	Area (m^2)	Hillslope Width (m)	Hillslope Length (m)	OFE Length (m)
1	1	Mesic Mixed Grassland - Grazed	Top-slope cobbly sandy loam				228
1	2	Mesic Mixed Grassland - Grazed	Side-slope clay loam	211,820	385	551	323
2	1	Mesic Mixed Grassland - Grazed	Top-slope cobbly sandy loam				168
2	2	Mesic Mixed Grassland - Grazed	Side-slope clay loam	153,015	684	224	56
3	1	Mesic Mixed Grassland - Grazed	Top-slope cobbly sandy loam				98
3	2	Mesic Mixed Grassland - Grazed	Side-slope clay loam	111,182	518	214	116
4	1	Mesic Mixed Grassland - Grazed	Top-slope cobbly sandy loam	184,992	322	574	574
5	1	Mesic Mixed Grassland - Grazed	Top-slope cobbly sandy loam	139,186	318	438	438
6	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				111
6	2	Mesic Mixed Grassland	Side-slope clay loam				66
6	3	Willow Riparian Shrubland	Bottom-slope clay loam	116,190	610	181	14
7	1	Xeric Tall Grass Prairie	Side-slope clay loam				74
7	2	Mesic Mixed Grassland	Side-slope clay loam	94,027	444	212	138
8	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				156
8	2	Mesic Mixed Grassland	Side-slope clay loam				23
8	3	Willow Riparian Shrubland	Side-slope clay loam	78,408	413	190	11
9	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				96
9	2	Improved Road	Improved road soil				8
9	3	Mesic Mixed Grassland	Side-slope clay loam				99
9	4	Mesic Mixed Grassland	Side-slope clay loam	167,034	654	255	52
10	1	Improved Road	Improved road soil	1,146	8	144	144
11	1	Improved Road	Improved road soil	1,486	8	186	186
12	1	Improved Road	Improved road soil	1,550	8	194	194
13	1	Improved Road	Improved road soil	1,075	8	134	134
14	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				240
14	2	Mesic Mixed Grassland	Side-slope clay loam				148
14	3	Willow Riparian Shrubland	Bottom-slope clay loam	83,821	223	421	32
15	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				462
15	2	Short Marsh	Side-slope clay loam				219
15	3	Mesic Mixed Grassland	Side-slope clay loam	223,052	273	816	136
16	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				636
16	2	Short Marsh	Top-slope cobbly sandy loam	205,643	250	821	185
17	1	Reclaimed Grassland	Side-slope clay loam				54
17	2	Improved Road	Improved road soil				6
17	3	Mesic Mixed Grassland	Side-slope clay loam				60
17	4	Willow Riparian Shrubland	Bottom-Sslope clay loam	63,620	489	130	10
18	1	Short Marsh	Top-slope cobbly sandy loam				132
18	2	Mesic Mixed Grassland	Side-slope clay loam				234
18	3	Willow Riparian Shrubland	Bottom-slope clay loam	107,534	275	391	25
19	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				285
19	2	Short Marsh	Side-slope clay loam	106,382	285	373	88
20	1	Improved Road	Improved road soil	4,824	8	603	603
21	1	Improved Road	Improved road soil	2,592	8	324	324
22	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				272
22	2	Mesic Mixed Grassland	Side-slope clay loam				105
22	3	Short Marsh	Side-slope clay loam	256,433	644	398	22
23	1	Reclaimed Grassland	Side-slope clay loam				20
23	2	Improved Road	Improved road soil				8
23	3	Mesic Mixed Grassland	Side-slope clay loam				60
23	4	Willow Riparian Shrubland	Bottom-Sslope clay loam	53,500	535	100	12
24	1	Improved Road	Improved road soil	2,285	16	141	141
25	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				110
25	2	Mesic Mixed Grassland	Side-slope clay loam				240
25	3	Improved Road	Improved road soil				10
25	4	Mesic Mixed Grassland	Side-slope clay loam				85
25	5	Willow Riparian Shrubland	Bottom-Sslope clay loam	154,969	332	467	23

Table 3. Hillslope and Overland Flow Element Dimensions, Habitat Type, and Soil Type for the Woman Creek Watershed WEPP Model, (continued)

26	1	Reclaimed Grassland	Side-slope clay loam				35
26	2	Mesic Mixed Grassland	Bottom-slope clay loam				62
26	3	Willow Riparian Shrubland	Bottom-slope clay loam	31,535	279	113	17
27	1	Xeric Tall Grass Prairie	Side-slope clay loam				113
27	2	Improved Road	Improved road soil				9
27	3	Mesic Mixed Grassland	Side-slope clay loam				175
27	4	Willow Riparian Shrubland	Bottom-Sslope clay loam	147,488	464	318	21
28	1	Mesic Mixed Grassland	Side-slope clay loam				220
28	2	Improved Road	Improved road soil				8
28	3	Reclaimed Grassland	Side-slope clay loam	45,787	150	305	77
29	1	Reclaimed Grassland	Side-slope clay loam				15
29	2	Improved Road	Improved road soil				2
29	3	Reclaimed Grassland	Side-slope clay loam	6,439	253	25	9
30	1	Reclaimed Grassland	Bottom-slope clay loam				18
30	2	Short Marsh	Bottom-slope clay loam	18,890	240	78	60
31	1	Reclaimed Grassland	Side-slope clay loam				127
31	2	Improved Road	Improved road soil				8
31	3	Reclaimed Grassland	Bottom-Sslope clay loam	31,672	156	203	68
32	1	Mesic Mixed Grassland	Side-slope clay loam				252
32	2	Mesic Mixed Grassland	Bottom-slope clay loam				286
32	3	Riparian Woodland	Bottom-slope clay loam	63,140	115	549	31
33	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				99
33	2	Improved Road	Improved road soil				268
33	3	Mesic Mixed Grassland	Side-slope clay loam	357,973	369	969	603
34	1	Mesic Mixed Grassland	Side-slope clay loam				419
34	2	Improved Road	Improved road soil				12
34	3	Mesic Mixed Grassland	Side-slope clay loam				175
34	4	Improved Road	Improved road soil				15
34	5	Mesic Mixed Grassland	Side-slope clay loam				81
34	6	Willow Riparian Shrubland	Side-slope clay loam	291,309	403	724	21
35	1	Reclaimed Grassland	Side-slope clay loam				73
35	2	Improved Road	Improved road soil				11
35	3	Mesic Mixed Grassland	Side-slope clay loam	311,252	296	1,050	966
36	1	Mesic Mixed Grassland	Bottom-slope clay loam				258
36	2	Leadplant Riparian Shrubland	Bottom-slope clay loam	85,547	275	347	91
37	1	Reclaimed Grassland	Side-slope clay loam				298
37	2	Leadplant Riparian Shrubland	Bottom-Sslope clay loam	151,225	473	320	22
38	1	Reclaimed Grassland	Bottom-slope clay loam				181
38	2	Leadplant Riparian Shrubland	Bottom-slope clay loam	55,240	318	173	13
39	1	Mesic Mixed Grassland	Bottom-Sslope clay loam				150
39	2	Short Marsh	Bottom-Sslope clay loam				121
39	3	Leadplant Riparian Shrubland	Bottom-Sslope clay loam	99,829	331	302	31
40	1	Mesic Mixed Grassland	Side-slope clay loam	43,301	512	85	85
41	1	Mesic Mixed Grassland	Side-slope clay loam	260,590	575	453	453
42	1	Mesic Mixed Grassland	Side-slope clay loam				98
42	2	Leadplant Riparian Shrubland	Side-slope clay loam	48,789	460	106	10
43	1	Mesic Mixed Grassland	Side-slope clay loam				365
43	2	Wet Meadow	Side-slope clay loam				236
43	3	Leadplant Riparian Shrubland	Bottom-Sslope clay loam	166,913	246	677	77
44	1	Mesic Mixed Grassland	Side-slope clay loam				289
44	2	Unimproved Road	Side-slope clay loam				8
44	3	Reclaimed Grassland	Side-slope clay loam	70,412	222	317	20
45	1	Mesic Mixed Grassland	Bottom-Sslope clay loam				144
45	2	Leadplant Riparian Shrubland	Bottom-Sslope clay loam	65,452	379	173	29
46	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				280
46	2	Mesic Mixed Grassland	Side-slope clay loam				424
46	3	Improved Road	Improved road soil				8
46	4	Mesic Mixed Grassland	Side-slope clay loam				83
46	5	Willow Riparian Shrubland	Bottom-slope clay loam	187,595	208	808	10
47	1	Mesic Mixed Grassland	Side-slope clay loam				45
47	2	Riparian Woodland	Side-slope clay loam				43
47	3	Mesic Mixed Grassland	Bottom-Sslope clay loam	39,857	365	109	21
48	1	Reclaimed Grassland	Bottom-slope clay loam	11,412	71	181	181
49	1	Improved Road	Improved road soil	2,664	8	333	333
50	1	Mesic Mixed Grassland	Side-slope clay loam				205
50	2	Improved Road	Improved road soil	21,939	103	213	8

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Table 4. Hillslope and Overland Flow Element Dimensions, Habitat Type, and Soil Type for the Walnut Creek Watershed WEPP Model

Hillslope Number	OFE Number	Habitat Type	Surface Soil Type	Area (m^2)	Hillslope Width (m)	Hillslope Length (m)	OFE Length (m)
1	1	Needle & Thread Grass Prairie	Top-slope cobbly sandy loam				146
1	2	Mesic Mixed Grassland	Side-slope clay loam				89
1	3	Wet Meadow	Side-slope clay loam	89,910	270	333	97
2	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				171
2	2	Mesic Mixed Grassland	Side-slope clay loam	28,786	111	268	97
3	1	Xeric Tall Grass Prairie	Side-slope clay loam				72
3	2	Mesic Mixed Grassland	Side-slope clay loam				304
3	3	Riparian Woodland	Bottom-slope clay loam	66,400	166	400	24
4	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				842
4	2	Wet Meadow	Top-slope cobbly sandy loam				243
4	3	Mesic Mixed Grassland	Side-slope clay loam				101
4	4	Short Marsh	Side-slope clay loam	107,242	86	1,247	61
5	1	Xeric Tall Grass Prairie	Side-slope clay loam				67
5	2	Mesic Mixed Grassland	Side-slope clay loam				125
5	3	Wet Meadow	Side-slope clay loam	51,513	223	231	39
6	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				256
6	2	Mesic Mixed Grassland	Side-slope clay loam				137
6	3	Improved Road	Improved road soil				8
6	4	Reclaimed Grassland	Side-slope clay loam				57
6	5	Riparian Woodland	Side-slope clay loam	70,518	146	483	25
7	1	Improved Road	Improved road soil	846	9	94	94
8	1	Improved Road	Improved road soil	1,136	8	142	142
9	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				109
9	2	Mesic Mixed Grassland	Side-slope clay loam				239
9	3	Riparian Woodland	Bottom-slope clay loam	152,934	426	359	11
10	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				174
10	2	Xeric Tall Grass Prairie	Side-slope clay loam				143
10	3	Mesic Mixed Grassland	Side-slope clay loam				174
10	4	Mesic / Road	Side-slope clay loam				4
10	5	Mesic Mixed Grassland	Side-slope clay loam				250
10	6	Reclaimed Grassland	Bottom-slope clay loam	127,986	155	826	80
11	1	Mesic Mixed Grassland	Side-slope clay loam	64,974	273	238	238
12	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				31
12	2	Mesic Mixed Grassland	Side-slope clay loam	76,395	430	178	146
13	1	Xeric Tall Grass Prairie	Side-slope clay loam				133
13	2	Mesic Mixed Grassland	Side-slope clay loam				299
13	3	Improved Road	Improved road soil				4
13	4	Mesic Mixed Grassland	Side-slope clay loam				102
13	5	Wet Meadow	Bottom-slope clay loam	131,225	223	588	50
14	1	Improved Road	Improved road soil	1,917	9	213	213
15	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				652
15	2	Mesic Mixed Grassland	Side-slope clay loam				204
15	3	Improved Road	Improved road soil				14
15	4	Reclaimed Grassland	Side-slope clay loam				36
15	5	Riparian Woodland	Side-slope clay loam	154,049	165	934	28
16	1	Mesic Mixed Grassland	Side-slope clay loam	7,528	80	94	94
17	1	Mesic Mixed Grassland	Side-slope clay loam				267
17	2	Riparian Woodland	Bottom-slope clay loam	66,010	230	287	20
18	1	Mesic Mixed Grassland	Side-slope clay loam				167
18	2	Riparian Woodland	Side-slope clay loam	45,860	248	184	17
19	1	Mesic Mixed Grassland	Side-slope clay loam				226
19	2	Wet Meadow	Bottom-slope clay loam	9,158	38	241	15
20	1	Mesic Mixed Grassland	Side-slope clay loam		24		212
20	2	Wet Meadow	Bottom-slope clay loam	6,138	24	258	44

Table 4. Hillslope and Overland Flow Element Dimensions, Habitat Type, and Soil Type for the Walnut Creek Watershed WEPP Model, (continued)

Hillslope Number	OFE Number	Habitat Type	Surface Soil Type	Area (m^2)	Hillslope Width (m)	Hillslope Length (m)	OFE Length (m)
21	1	Mesic Mixed Grassland	Side-slope clay loam				604
21	2	Short Marsh	Side-slope clay loam	113,759	181	629	24
22	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				274
22	2	Mesic Mixed Grassland	Side-slope clay loam				183
22	3	Wet Meadow	Side-slope clay loam	147,886	305	485	28
23	1	Mesic Mixed Grassland	Side-slope clay loam	36,072	167	216	216
24	1	Improved Road	Improved road soil				6
24	2	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				369
24	3	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				58
24	4	Mesic Mixed Grassland	Side-slope clay loam				87
24	5	Wet Meadow	Side-slope clay loam	74,022	115	644	123
25	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				109
25	2	Mesic Mixed Grassland	Side-slope clay loam				177
25	3	Wet Meadow	Side-slope clay loam	10,824	34	318	32
26	1	Improved Road	Improved road soil				5
26	2	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				273
26	3	Mesic Mixed Grassland	Side-slope clay loam				102
26	4	Wet Meadow	Side-slope clay loam	51,955	121	429	49
27	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				35
27	2	Mesic Mixed Grassland	Side-slope clay loam				378
27	3	Willow Riparian Shrubland	Bottom-slope clay loam	147,339	301	489	76
28	1	Mesic Mixed Grassland	Side-slope clay loam				264
28	2	Reclaimed Grassland	Side-slope clay loam	62,049	129	481	217
29	1	Reclaimed Grassland	Top-slope cobbly sandy loam				162
29	2	Mesic Mixed Grassland	Side-slope clay loam				218
29	3	Wet Meadow	Side-slope clay loam	149,780	364	411	31
30	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				124
30	2	Mesic Mixed Grassland	Side-slope clay loam				129
30	3	Wet Meadow	Side-slope clay loam	30,053	95	316	63
31	1	Improved Road	Improved road soil	3,976	7	568	568
32	1	Mesic Mixed Grassland	Side-slope clay loam				239
32	2	Wet Meadow	Bottom-slope clay loam	18,957	71	267	28
33	1	Needle & Threadgrass Prairie	Top-slope cobbly sandy loam				38
33	2	Mesic Mixed Grassland	Side-slope clay loam				201
33	3	Wet Meadow	Haverson Loam	21,838	82	266	27
34	1	Needle & Threadgrass Prairie	Top-slope cobbly sandy loam				45
34	2	Mesic Mixed Grassland	Side-slope clay loam				128
34	3	Wet Meadow	Bottom-slope clay loam	30,257	120	252	79
35	1	Improved Road	Improved road soil				8
35	2	Mesic Mixed Grassland	Side-slope clay loam				253
35	3	Wet Meadow	Side-slope clay loam	13,488	48	281	20
36	1	Improved Road	Improved road soil				8
36	2	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				306
36	3	Reclaimed Grassland	Side-slope clay loam				40
36	4	Riparian Woodland	Side-slope clay loam	39,285	97	405	51
37	1	Mesic Mixed Grassland	Side-slope clay loam	125,130	485	258	258
38	1	Reclaimed Grassland	Side-slope clay loam				35
38	2	Mesic Mixed Grassland	Side-slope clay loam				99
38	3	Willow Riparian Shrubland	Side-slope clay loam	28,748	93	309	175
39	1	Needle & Threadgrass Prairie	Top-slope cobbly sandy loam				45
39	2	Wet Meadow	Side-slope clay loam				232
39	3	Mesic Mixed Grassland	Side-slope clay loam				130
39	4	Willow Riparian Shrubland	Bottom-slope clay loam	105,025	244	430	23
40	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				357
40	2	Mesic Mixed Grassland	Side-slope clay loam				182
40	3	Wet Meadow	Side-slope clay loam	98,130	171	574	35

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Table 4. Hillslope and Overland Flow Element Dimensions, Habitat Type, and Soil Type for the Walnut Creek Watershed WEPP Model, (continued)

Hillslope Number	OFE Number	Habitat Type	Surface Soil Type	Area (m^2)	Hillslope Width (m)	Hillslope Length (m)	OFE Length (m)
41	1	Improved Road	Improved Road Soil	1,584	8	198	198
42	1	Reclaimed Grassland	Top-slope cobbly sandy loam				82
42	2	Reclaimed Grassland	Side-slope clay loam				50
42	3	Improved Road	Improved road soil				9
42	4	Reclaimed Grassland	Side-slope clay loam				80
42	5	Improved Road	Improved road soil				41
42	6	Reclaimed Grassland	Side-slope clay loam				61
42	7	Willow Riparian Shrubland	Side-slope clay loam	18,497	53	348	26
43	1	Reclaimed Grassland	Side-slope clay loam				34
43	2	Willow Riparian Shrubland	Side-slope clay loam	6,477	121	54	20
44	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				244
44	2	Improved Road	Improved road soil				10
44	3	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				130
44	4	Mesic Mixed Grassland	Side-slope clay loam				138
44	5	Wet Meadow	Side-slope clay loam	30,085	53	568	45
45	1	Reclaimed Grassland	Top-slope cobbly sandy loam				168
45	2	Mesic Mixed Grassland	Side-slope clay loam				70
45	3	Improved Road	Improved road soil				4
45	4	Reclaimed Grassland	Side-slope clay loam				39
45	5	Willow Riparian Shrubland	Side-slope clay loam	56,354	162	348	67
46	1	Mesic Mixed Grassland	Side-slope clay loam				61
46	2	Improved Road	Improved road soil				35
46	3	Mesic Mixed Grassland	Side-slope clay loam				276
46	4	Willow Riparian Shrubland	Side-slope clay loam	52,260	134	390	18
47	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				58
47	2	Mesic Mixed Grassland	Side-slope clay loam				149
47	3	Wet Meadow	Bottom-slope clay loam	48,992	196	250	43
48	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				65
48	2	Mesic Mixed Grassland	Side-slope clay loam	102,141	470	217	152
49	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				88
49	2	Mesic Mixed Grassland	Side-slope clay loam				117
49	3	Willow Riparian Shrubland	Haverson Loam	23,928	99	242	36
50	1	Improved Road	Improved road soil				8
50	2	Reclaimed Grassland	Side-slope clay loam				34
50	3	Mesic Mixed Grassland	Side-slope clay loam				172
50	4	Willow Riparian Shrubland	Side-slope clay loam	30,058	113	266	52
51	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				65
51	2	Mesic Mixed Grassland	Side-slope clay loam				531
51	3	Wet Meadow	Side-slope clay loam	143,714	181	794	198
52	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				150
52	2	Mesic Mixed Grassland	Side-slope clay loam				78
52	3	Reclaimed Grassland	Side-slope clay loam				125
52	4	Willow Riparian Shrubland	Bottom-slope clay loam	48,546	109	445	92
53	1	Improved Road	Improved road soil	4,428	6	738	738
54	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				212
54	2	Mesic Mixed Grassland	Side-slope clay loam				120
54	3	Riparian Woodland	Bottom-slope clay loam	77,393	212	365	33
55	1	Needle & Threadgrass Prairie	Top-slope cobbly sandy loam				41
55	2	Wet Meadow	Side-slope clay loam				159
55	3	Mesic Mixed Grassland	Side-slope clay loam	67,754	281	241	41
56	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				57
56	2	Reclaimed Grassland	Side-slope clay loam	24,912	173	144	87
57	1	Improved Road	Improved road soil				606
57	2	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				79
57	3	Reclaimed Grassland	Top-slope cobbly sandy loam				58
57	4	Reclaimed Grassland	Side-slope clay loam	128,590	154	835	92
58	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				97
58	2	Mesic Mixed Grassland	Side-slope clay loam				136
58	3	Reclaimed Grassland	Side-slope clay loam				43
58	4	Improved Road	Improved road soil				4
58	5	Reclaimed Grassland	Side-slope clay loam				21
58	6	Willow Riparian Shrubland	Haverson Loam	66,744	192	348	46

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Table 4. Hillslope and Overland Flow Element Dimensions, Habitat Type, and Soil Type for the Walnut Creek Watershed WEPP Model,(continued)

Hillslope Number	OFE Number	Habitat Type	Surface Soil Type	Area (m^2)	Hillslope Width (m)	Hillslope Length (m)	OFE Length (m)
59	1	Reclaimed Grassland	Side-slope clay loam				29
59	2	Improved Road	Improved road soil				8
59	3	Reclaimed Grassland	Side-slope clay loam				39
59	4	Short Upland Shrubland	Side-slope clay loam				20
59	5	Tall Marsh	Side-slope clay loam	8,851	60	148	52
60	1	Reclaimed Grassland	Side-slope clay loam				130
60	2	Improved Road	Improved Road Soil				10
60	3	Reclaimed Grassland	Side-slope clay loam				59
60	4	Riparian Woodland	Side-slope clay loam	58,535	239	245	45
61	1	Improved Road	Improved road soil	2,569	7	367	367
62	1	Reclaimed Grassland	Top-slope cobbly sandy loam				153
62	2	Reclaimed Grassland	Side-slope clay loam				185
62	3	Mesic Mixed Grassland	Side-slope clay loam	42,935	86	499	161
63	1	Xeric Tall Grass Prairie	Side-slope clay loam				185
63	2	Reclaimed Grassland	Side-slope clay loam				103
63	3	Improved Road	Improved road soil				10
63	4	Mesic Mixed Grassland	Side-slope clay loam	44,154	126	350	52
64	1	Reclaimed Grassland	Side-slope clay loam	7,650	150	51	51
65	1	Reclaimed Grassland	Side-slope clay loam	5,670	105	54	54
66	1	Mesic Mixed Grassland	Side-slope clay loam		85		140
66	2	Reclaimed Grassland	Side-slope clay loam	22,270	85	262	122
67	1	Needle & Threadgrass Prairie	Top-slope cobbly sandy loam		49		81
67	2	Mesic Mixed Grassland	Side-slope clay loam	11,677	49	238	157
68	1	Needle & Threadgrass Prairie	Top-slope cobbly sandy loam				128
68	2	Xeric Tall Grass Prairie	Side-slope clay loam				49
68	3	Mesic Mixed Grassland	Side-slope clay loam	33,580	115	292	115
69	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				117
69	2	Xeric Tall Grass Prairie	Side-slope clay loam				43
69	3	Reclaimed Grassland	Side-slope clay loam				35
69	4	Disturbed / Improad	Side-slope clay loam	14,737	66	223	28
71	1	Improved Road	Improved road soil	1,599	13	123	123
72	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				148
72	2	Mesic Mixed Grassland	Side-slope clay loam				120
72	3	Reclaimed Grassland	Side-slope clay loam	22,778	75	304	35
73	1	Reclaimed Grassland	Top-slope cobbly sandy loam				43
73	2	Mesic Mixed Grassland	Side-slope clay loam				76
73	3	Reclaimed Grassland	Side-slope clay loam				99
73	4	Improved Road	Improved road soil	20,331	79	257	39
74	1	Reclaimed Grassland	Side-slope clay loam				47
74	2	Improved Road	Improved road soil	4,439	51	87	40
75	1	Needle & Threadgrass Prairie	Top-slope cobbly sandy loam				58
75	2	Mesic Mixed Grassland	Side-slope clay loam	29,698	252	118	60
76	1	Needle & Threadgrass Prairie	Top-slope cobbly sandy loam				93
76	2	Reclaimed Grassland	Side-slope clay loam				40
76	3	Improved Road	Improved road soil				15
76	4	Reclaimed Grassland	Side-slope clay loam	13,718	76	180	32
78	1	Reclaimed Grassland	Top-slope cobbly sandy loam				80
78	2	Reclaimed Grassland	Side-slope clay loam				32
78	3	Improved Road	Improved road soil				15
78	4	Reclaimed Grassland	Side-slope clay loam	16,256	90	181	54
79	1	Mesic Mixed Grassland	Side-slope clay loam	21,252	308	69	69
80	1	Reclaimed Grassland	Top-slope cobbly sandy loam				77
80	2	Mesic Mixed Grassland	Side-slope clay loam				68
80	3	Reclaimed Grassland	Side-slope clay loam				81
80	4	Wet Meadow	Side-slope clay loam	22,855	94	243	17

Table 4. Hillslope and Overland Flow Element Dimensions, Habitat Type, and Soil Type for the Walnut Creek Watershed WEPP Model, (continued)

Hillslope Number	OFE Number	Habitat Type	Surface Soil Type	Area (m^2)	Hillslope Width (m)	Hillslope Length (m)	OFE Length (m)
81	1	Improved Road	Improved road soil	1,180	10	118	118
84	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				31
84	2	Xeric Tall Grass Prairie	Side-slope clay loam				53
84	3	Mesic Mixed Grassland	Side-slope clay loam				210
84	4	Wet Meadow	Side-slope clay loam				287
84	5	Willow Riparian Shrubland	Bottom-slope clay loam	105,828	165	640	49
85	1	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				127
85	2	Mesic Mixed Grassland	Side-slope clay loam				136
85	3	Wet Meadow	Side-slope clay loam	51,676	155	333	21
86	1	Improved Road	Side-slope clay loam				28
86	2	Reclaimed Grassland	Improved road soil				60
86	3	Improved Road	Side-slope clay loam				10
86	4	Reclaimed Grassland	Side-slope clay loam				27
86	5	Mesic Mixed Grassland	Side-slope clay loam				244
86	6	Wet Meadow	Side-slope clay loam	30,800	77	400	31
87	1	Xeric Tall Grass Prairie	Side-slope clay loam	174,660	355	492	190
88	1	Reclaimed Grassland	Top-slope cobbly sandy loam				69
88	2	Reclaimed Grassland	Side-slope clay loam				23
88	3	Improved Road	Improved road soil				15
88	4	Reclaimed Grassland	Improved road soil				63
88	5	Smarsh	Side-slope clay loam	29,306	138	212	42
99	1	Improved Road	Improved road soil				134
99	2	Xeric Tall Grass Prairie	Top-slope cobbly sandy loam				29
99	3	Reclaimed Grassland	Top-slope cobbly sandy loam				50
99	4	Improved Road	Improved road soil				45
99	5	Willow Riparian Shrubland	Side-slope clay loam	8,840	65	136	12

Table 5. Hillslope and Overland Flow Element Dimensions, Habitat Type, and Soil Type for the South Interceptor Ditch Watershed WEPP Model

Hillslope Number	OFE Number	Habitat Type	Surface / Soil Type	Area (m^2)	Hillslope Width (m)	Hillslope Length (m)	OFE Length (m)
1	1	Mesic Mixed Grassland	Top-slope cobbly sandy loam				54
1	2	Mesic Mixed Grassland	Side-slope clay loam				30
1	3	Riparian Woodland	Side-slope clay loam	43,684	326	134	50
3	2	Disturbed and Developed Areas	Not Modeled (Monitoring Data Used)	43,194	138	313	313
4	2	Disturbed and Developed Areas	Not Modeled (Monitoring Data Used)	20,708	167	124	124
5	2	Disturbed and Developed Areas	Not Modeled (Monitoring Data Used)	46,805	195	239	231
6	1	Improved Gravel Road	Improved road soil	524	4	131	131
7	1	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam				44
7	2	Wet Meadow	Top-slope cobbly sandy loam				30
7	3	Wet Meadow	Side-slope clay loam				20
7	4	Reclaimed Mixed Grassland	Side-slope clay loam	18,000	120	150	58
9	1	Disturbed and Developed Areas	Top-slope cobbly sandy loam				53
9	2	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam				52
9	3	Reclaimed Mixed Grassland	Side-slope clay loam				46
9	4	Annual Grass and Forbs	Side-slope clay loam	28,063	133	211	60
10	1	Reclaimed Mixed Grassland	Side-slope clay loam				27
10	2	Annual Grass and Forbs	Side-slope clay loam				44
10	3	Unimproved Road	Side-slope clay loam				8
10	4	Annual Grass and Forbs	Side-slope clay loam	12,200	100	122	45
11	1	Improved Gravel Road	Improved road soil	696	6	116	116
12	1	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam				42
12	2	Reclaimed Mixed Grassland	Side-slope clay loam				107
12	3	Improved Gravel Road	Improved road soil				23
12	4	Annual Grass and Forbs	Side-slope clay loam	8,550	38	225	53
13	1	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam				42
13	2	Reclaimed Mixed Grassland	Side-slope clay loam				79
13	3	Improved Gravel Road	Improved road soil	36,836	284	129	8
14	1	Improved Gravel Road	Improved road soil				4
14	2	Annual Grass and Forbs	Side-slope clay loam	24,332	316	77	73
15	1	Paved Areas	Concrete, Asphalt, Aggregate				32
15	2	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam				66
15	3	Reclaimed Mixed Grassland	Side-slope clay loam				37
15	4	Improved Gravel Road	Improved road soil	50,050	350	143	8
16	1	Improved Gravel Road	Improved road soil				4
16	2	Mesic Mixed Grassland	Side-slope clay loam	42,458	299	142	138
17	1	Improved Gravel Road	Improved road soil				126
17	2	Reclaimed Grassland	Gravel/Denver-Kutch-Midway clay loam	1,655	5	331	205
18	1	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam				113
18	2	Reclaimed Mixed Grassland	Side-slope clay loam				40
18	3	Improved road/Shooting range	Improved road soil				20
18	4	Reclaimed Mixed Grassland	Side-slope clay loam				50
18	5	Mesic Mixed Grassland	Side-slope clay loam				165
18	6	Unimproved Road	Side-slope clay loam				3
18	7	Reclaimed Mixed Grassland	Side-slope clay loam	84,996	207	411	20
19	1	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam				172
19	2	Improved road/Shooting range	Improved road soil				27
19	3	Reclaimed Mixed Grassland	Side-slope clay loam				255
19	4	Unimproved Road	Side-slope clay loam				2
19	5	Reclaimed Mixed Grassland	Side-slope clay loam	35,224	74	476	20
20	1	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam				66
20	2	Reclaimed Mixed Grassland	Side-slope clay loam				72
20	3	Mesic Mixed Grassland	Side-slope clay loam				194
20	4	Unimproved Road	Side-slope clay loam				2
20	5	Mesic Mixed Grassland	Side-slope clay loam	66,717	189	353	19
21	1	Paved Areas	East access road	5,930	593	10	10
22	1	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam	124,396	274	454	454
23	1	Reclaimed Mixed Grassland	Top-slope cobbly sandy loam				50
23	2	Reclaimed Mixed Grassland	Side-slope clay loam				34
23	3	Mesic Mixed Grassland	Side-slope clay loam	23,326	218	107	22
25	1	Mesic Mixed Grassland	Side-slope clay loam	6,327	57	111	111
26	1	Mesic Mixed Grassland	Side-slope clay loam	9,375	75	125	125
27	1	Mesic Mixed Grassland	Side-slope clay loam	858	22	39	39

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Table 6. Flow Routing Scheme for North Walnut Creek and South Walnut Creek in the HEC-6T Models

Stream	Return Interval (Years)	Percentage of Flow Routed Through Bypass	Percentage of Flow Routed Through Ponds
North Walnut Creek	1 and 2	99.9	0.1
	10	95	5
	15	30	70
	100	50	50
South Walnut Creek	1 and 2	99.9	0.1
	10	95	5
	15	60	40
	100	50	50

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Table 7. Summary of 100-Year Runoff and Erosion for the Woman Creek Watershed

HILLSLOPE	MEAN ANNUAL PRECIPITAION	MEAN ANNUAL RAIN RUNOFF	MEAN ANNUAL SNOW RUNOFF	MEAN ANNUAL RUNOFF	AVERAGE SEDIMENT YIELD	TOTAL SEDIMENT YIELD	HILLSLOPE WIDTH	HILLSLOPE AREA	AVERAGE ANNUAL SOIL LOSS	AVERAGE SUSPENDED SOLIDS	RONOFF COEFFICIENT
		(mm)	(mm)	(mm)	(kg/m)	(kg)	(m)	(hectares)	(tonnes/ha)	(mg/ L)	
1	370	7.98	2.04	10.02	12.895	4,965	385	21.213	0.234	2,336	0.027
2	370	11.4	1.51	12.91	9.915	6,782	684	15.322	0.443	3,428	0.035
3	370	13.88	2.73	16.61	13.142	6,808	518	11.085	0.614	3,697	0.045
4	370	4.47	0.08	4.55	4.81	1,549	322	18.483	0.084	1,842	0.012
5	370	4.57	0.08	4.65	3.358	1,068	318	13.928	0.077	1,649	0.013
6	370	13.75	2.19	15.94	2.12	1,293	610	11.651	0.111	696	0.043
7	370	21.19	4.93	26.12	2.671	1,186	444	9.28	0.128	489	0.071
8	370	19.82	2.12	21.94	2.405	993	413	7.847	0.127	577	0.059
9	370	16.11	2.88	18.99	7.831	5,121	654	16.677	0.307	1,617	0.051
10	370	99.36	17.64	117	77.069	617	8	0.115	5.352	4,582	0.316
11	370	90.49	15.74	106.23	74.463	596	8	0.149	4.003	3,764	0.287
12	370	86.31	15.09	101.4	113.306	906	8	0.155	5.841	5,767	0.274
13	370	95.28	16.27	111.55	60.062	480	8	0.107	4.482	4,026	0.301
14	370	16.33	2.3	18.63	11.482	2,560	223	9.366	0.273	1,467	0.050
15	370	10.31	4.25	14.56	16.712	4,562	273	22.304	0.205	1,405	0.039
16	370	16.46	7.73	24.19	2.349	587	250	20.525	0.029	118	0.065
17	370	25.07	4.96	30.03	3.235	1,582	489	6.357	0.249	829	0.081
18	370	17.84	2.29	20.13	9.536	2,622	275	10.752	0.244	1,212	0.054
19	370	12.08	3.12	15.2	2.03	579	285	10.63	0.054	358	0.041
20	370	64.75	11.8	76.55	170.285	1,362	8	0.482	2.824	3,692	0.207
21	370	80.52	14.59	95.11	273.666	2,189	8	0.259	8.446	8,888	0.257
22	370	10.29	2.3	12.59	4.426	2,851	644	25.696	0.111	881	0.034
23	370	30.21	4.56	34.77	4.114	2,201	535	5.35	0.411	1,183	0.094
24	370	91.26	15.63	106.89	72.509	580	8	0.113	5.142	4,802	0.289
25	370	14.38	1.85	16.23	25.163	8,354	332	15.538	0.538	3,313	0.044
26	370	20.14	3.61	23.75	0.949	265	279	3.181	0.083	351	0.064
27	370	13.62	2.26	15.88	18.225	8,456	464	14.755	0.573	3,609	0.043
28	370	21.18	4.98	26.16	6.163	924	150	4.575	0.202	772	0.071
29	370	39.89	6.77	46.66	0.359	91	253	0.658	0.138	296	0.126
30	370	24.22	2.45	26.67	1.003	241	240	1.872	0.129	482	0.072
31	370	16.6	1.89	18.49	6.03	941	156	3.167	0.297	1,607	0.050
32	370	12.94	2.24	15.18	8.627	992	115	6.313	0.157	1,035	0.041
33	370	12.03	2.83	14.86	18.941	6,989	369	35.793	0.195	1,314	0.040
34	370	7.04	1.59	8.63	16.519	6,657	403	29.137	0.228	2,647	0.023
35	370	11.89	2.1	13.99	15.939	4,718	296	31.08	0.152	1,085	0.038

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Table 7. Summary of 100-Year Runoff and Erosion for the Woman Creek Watershed, (continued)

HILLSLOPE	MEAN ANNUAL PRECIPITAION	MEAN ANNUAL RAIN RUNOFF	MEAN ANNUAL SNOW RUNOFF	MEAN ANNUAL RUNOFF	AVERAGE SEDIMENT YIELD	TOTAL SEDIMENT YIELD	HILLSLOPE WIDTH	HILLSLOPE AREA	AVERAGE ANNUAL SOIL LOSS	AVERAGE SUSPENDED SOLIDS	RONOFF COEFFICIENT
36	370	13.86	3.36	17.22	2.767	761	275	9.542	0.08	463	0.047
37	370	13.53	3.14	16.67	1.129	534	473	15.136	0.035	212	0.045
38	370	16.08	2.45	18.53	0.81	258	318	5.533	0.047	251	0.050
39	370	9.1	2.41	11.51	1.441	477	331	9.996	0.048	415	0.031
40	376	30.95	3	33.95	1.823	933	512	4.352	0.214	632	0.090
41	370	11.81	1.84	13.65	3.526	2,028	575	26.048	0.078	570	0.037
42	370	10.17	1.57	11.74	0.119	55	460	4.876	0.011	96	0.032
43	370	10.79	2.67	13.46	12.846	3,160	246	16.679	0.189	1,408	0.036
44	370	11.45	1.65	13.1	5.702	1,266	222	7.037	0.18	1,373	0.035
45	370	17.12	2.41	19.53	1.381	522	378	6.539	0.08	409	0.053
46	370	13.45	1.98	15.43	37.478	7,795	208	16.12	0.484	3,134	0.042
47	370	24.9	4.78	29.68	1.232	450	365	3.978	0.113	381	0.080
48	370	17.59	2.5	20.09	0.624	44	71	1.143	0.039	193	0.054
49	370	88.77	16.46	105.23	258.509	2,068	8	0.266	7.763	7,388	0.284
50	370	15.49	1.88	17.37	4.385	452	103	2.194	0.206	1,185	0.047
ESTIMATED ANNUAL WOMAN CREEK WATERSHED SEDIMENT YIELD (TONNES/HA)						0.221					
ESTIMATED ANNUAL WOMAN CREEK WATERSHED SEDIMENT YIELD (TONS/ACRE)						0.099					
ESTIMATED ANNUAL WOMAN CREEK WATERSHED EROSION DEPTH (mm)						0.025					
ESTIMATED ANNUAL WOMAN CREEK RUNOFF COEFFICIENT						0.043					

WOMAN CREEK LANDUSE	100-YEAR AVERAGE SEDIMENT YIELDS (TONNES/HA)	100-YEAR AVERAGE SUSPENDED SOLIDS (MG/L)	100-YEAR AVERAGE ANNUAL RUNOFF (MM)	100-YEAR AVERAGE ANNUAL RUNOFF COEFFICIENT	PERCENT CONTRIBUTION TO TOTAL SOIL LOSS
IMPROVED ROADS	5.35	5,364	102	0.220	8%
HILLSLOPES WITH IMPROVED ROADS	0.29	1,712	21	0.043	49%
GRAZED HILLSLOPES	0.26	2,590	10	0.025	19%
HILLSLOPES WITH MINIMAL DISTURBANCE	0.11	613	19	0.047	25%

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Table 8. Summary of 100-Year Runoff and Erosion for the South Interceptor Ditch Watershed

HILLSLOPE	MEAN ANNUAL PRECIPITATION	MEAN ANNUAL RAIN RUNOFF	MEAN ANNUAL SNOW RUNOFF	MEAN ANNUAL RUNOFF	AVERAGE SEDIMENT YIELD	TOTAL SEDIMENT YIELD	HILLSLOPE WIDTH	HILLSLOPE AREA	AVERAGE ANNUAL SOIL LOSS	AVERAGE SUSPENDED SOLIDS	RUNOFF COEFICIENT
	(mm)	(mm)	(mm)	(mm)	(kg/m)	(kg)	(m)	(hectares)	(tonnes/ha)	(mg/l)	
1	370	18.1	1.9	20.0	5.370	1,751	326	4.368	0.401	2,002	0.054
6	370	97.2	17.5	115	56.677	227	4	0.052	4.359	3,803	0.310
7	370	22.0	2.8	24.8	0.098	347	120	1.8	0.193	777	0.067
9	370	26.2	2.5	28.7	9.851	1,310	133	2.806	0.467	1,629	0.077
10	370	23.1	2.7	25.7	3.327	346	104	1.217	0.284	1,105	0.070
11	370	93.4	15.8	109	99.775	599	6	0.07	8.563	7,828	0.295
12	370	21.1	2.6	23.6	12.502	635	38	0.855	0.743	3,143	0.064
13	370	24.0	2.5	26.5	4.925	1,399	284	3.664	0.382	1,438	0.072
14	370	28.6	2.7	31.2	2.138	676	316	2.433	0.278	889	0.084
15	370	28.1	2.3	30.4	12.586	4,405	350	5.005	0.880	2,899	0.082
16	370	24.8	2.1	26.8	6.098	1,823	299	4.246	0.429	1,600	0.073
17	370	47.9	5.6	53	77.482	387	5	0.166	2.334	4,368	0.144
18	370	15.8	1.8	17.6	22.396	4,636	207	8.508	0.545	3,094	0.048
19	370	15.0	2.0	17.0	17.815	1,318	74	3.522	0.374	2,207	0.046
20	370	15.6	1.6	17.3	16.454	3,110	189	6.672	0.466	2,702	0.047
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.593	0.000	0	0.731
22	370	4.8	0.2	5.0	0.085	23	274	12.44	0.002	38	0.013
23	370	25.0	3.2	28.2	2.434	531	218	2.333	0.227	807	0.076
25	370	25.5	2.8	28.3	2.923	167	57	0.633	0.263	930	0.076
26	370	24.4	2.8	27.2	3.471	260	75	0.938	0.278	1,019	0.074
27	370	29.3	2.7	31.9	0.291	6	22	0.086	0.075	234.	0.086

ESTIMATED ANNUAL SID WATERSHED SEDIMENT YIELD (TONNES/HA)	0.384
ESTIMATED ANNUAL SID WATERSHED SEDIMENT YIELD (TONS/ACRE)	0.171
ESTIMATED ANNUAL SID WATERSHED EROSION DEPTH (mm)	0.043
ESTIMATED ANNUAL SID RUNOFF COEFFICIENT	0.060

SID LAND USE	YIELDS (TONNES/HA)	SUSPENDED SOLIDS (MG/L)	RUNOFF (MM)	COEFFICIENT	CONTRIBUTION TO
PAVED ROADS	0.0	0.0	270	0.731	0%
HILLSLOPES WITH PAVED AREAS	2,858	2,264	30	0.080	24%
IMPROVED ROADS	6.456	5,816	112	0.302	3%
HILLSLOPES WITH IMPROVED ROADS	0.785	2,422	29.9	0.081	40%
HILLSLOPES WITH UNIMPROVED ROADS	0.375	2,005	30.0	0.054	20%
HILLSLOPES WITH MINIMAL DISTUBANCE	0.205	829	23.6	0.064	13%

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Table 9. Summary of 100-Year Runoff and Erosion for the Walnut Creek Watershed

HILLSLOPE	MEAN ANNUAL PRECIPITATION	MEAN ANNUAL RAIN RUNOFF	MEAN ANNUAL SNOW RUNOFF	MEAN ANNUAL RUNOFF	AVERAGE SEDIMENT YIELD	TOTAL SEDIMENT YIELD	HILLSLOPE WIDTH	HILLSLOPE AREA	AVERAGE ANNUAL SOIL LOSS	AVERAGE SUSPENDED SOLIDS	RUNOFF COEFFICIENT
	(mm)	(mm)	(mm)	(mm)	(kg/m)	(kg)	(m)	(hectares)	(tonnes/ha)	(mg/L)	
1	370	11.82	2.28	14.1	8.167	2,205	270	8.964	0.246	1,745	0.038
2	370	12.2	1.99	14.19	3.931	436	111	2.975	0.147	1,034	0.038
3	370	13.34	1.84	15.18	10.285	1,707	166	6.64	0.257	1,694	0.041
4	370	3.73	0.73	4.46	10.835	932	86	10.724	0.087	1,948	0.012
5	370	12.22	2.22	14.44	2.345	523	223	5.151	0.102	703	0.039
6	370	9.76	1.68	11.44	20.21	2,951	146	7.052	0.418	3,657	0.031
7	370	103.32	17.87	121.19	74.322	669	9	0.085	7.907	6,493	0.327
8	370	90.45	15.53	105.98	108.114	865	8	0.114	7.614	7,159	0.286
9	370	14.97	2.6	17.57	6.617	2,819	426	15.293	0.184	1,049	0.047
10	370	9.37	1.84	11.21	16.075	2,492	155	12.788	0.195	1,738	0.030
11	370	16.14	2.36	18.5	6.874	1,877	273	6.497	0.289	1,561	0.050
12	370	18.44	2.8	21.24	3.878	1,668	430	7.611	0.219	1,032	0.057
13	370	8.17	1.91	10.08	10.189	2,272	223	13.112	0.173	1,719	0.027
14	370	86.15	15.12	101.27	94.262	848	9	0.192	4.425	4,363	0.274
15	370	5.46	0.87	6.33	19.048	3,143	165	15.411	0.204	3,222	0.017
16	370	20.21	2.68	22.89	0.22	18	80	0.752	0.023	102	0.062
17	370	7.58	1.52	9.1	2.054	472	230	6.601	0.072	787	0.025
18	370	15.63	2.62	18.25	0.632	157	248	4.563	0.034	188	0.049
19	370	6.95	1.21	8.16	0.649	25	38	0.916	0.027	330	0.022
20	370	8.24	1.87	10.11	0.284	7	24	0.614	0.011	110	0.027
21	370	4.07	0.69	4.76	1.13	205	181	11.367	0.018	378	0.013
22	370	9.81	1.64	11.45	12.836	3,915	305	14.792	0.265	2,311	0.031
23	370	13.46	1.98	15.44	0.258	43	167	3.607	0.012	77	0.042
24	370	12.43	1.15	13.58	36.576	4,206	115	7.394	0.569	4,189	0.037
25	370	14.73	3.13	17.86	10.948	372	34	1.081	0.344	1,928	0.048
26	370	14.13	1.31	15.44	19.029	2,321	122	5.234	0.444	2,873	0.042
27	370	11.42	1.7	13.12	15.395	4,634	301	14.719	0.315	2,400	0.035
28	370	6.94	1.8	8.74	3.573	461	129	6.205	0.074	850	0.024
29	370	11.51	2.24	13.75	22.623	8,235	364	14.96	0.55	4,003	0.037
30	370	12.88	2.82	15.7	7.103	675	95	3.002	0.225	1,432	0.042
31	370	52.19	9.09	61.28	28.772	201	7	0.398	0.507	826	0.166
32	370	7.75	1.55	9.3	1.818	129	71	1.896	0.068	732	0.025
33	370	14.24	2.21	16.45	8.192	672	82	2.181	0.308	1,872	0.044
34	370	13.55	2.1	15.65	6.097	732	120	3.024	0.242	1,546	0.042
35	370	18.17	2.1	20.27	14.058	675	48	1.349	0.5	2,468	0.055

Table 9. Summary of 100-Year Runoff and Erosion for the Walnut Creek Watershed, (continued)

HILLSLOPE	MEAN ANNUAL PRECIPITATION	MEAN ANNUAL RAIN RUNOFF	MEAN ANNUAL SNOW RUNOFF	MEAN ANNUAL RUNOFF	AVERAGE SEDIMENT YIELD	TOTAL SEDIMENT YIELD	HILLSLOPE WIDTH	HILLSLOPE AREA	AVERAGE ANNUAL SOIL LOSS	AVERAGE SUSPENDED SOLIDS	RUNOFF COEFFICIENT
	(mm)	(mm)	(mm)	(mm)	(kg/m)	(kg)	(m)	(hectares)	(tonnes/ha)	(mg/L)	
36	370	17.57	1.68	19.25	17.895	1,736	97	3.928	0.442	2,296	0.052
37	370	15.27	2.23	17.5	3.383	1,641	485	12.513	0.131	749	0.047
38	370	13.8	4.13	17.93	2.423	225	93	2.874	0.078	437	0.048
39	370	12.1	1.55	13.65	18.005	4,411	245	10.559	0.418	3,061	0.037
40	370	8.29	1.52	9.81	11.435	1,955	171	9.815	0.199	2,031	0.027
41	370	167.66	55.13	222.79	81.805	654	8	0.158	4.132	1,859	0.602
42	370	14.65	2.11	16.76	16.686	884	53	1.844	0.479	2,862	0.045
43	370	22.16	2.4	24.56	0.533	65	121	0.653	0.099	402	0.066
44	370	10.69	1.97	12.66	22.185	1,176	53	2.952	0.398	3,146	0.034
45	370	15.34	1.29	16.63	18.104	2,933	162	5.638	0.52	3,128	0.045
46	370	17.33	2.38	19.71	27.554	3,692	134	5.226	0.707	3,584	0.053
47	370	17.24	3.36	20.6	8.767	1,718	196	4.9	0.351	1,702	0.056
48	370	18.09	3.68	21.77	3.782	1,777	470	10.199	0.174	801	0.059
49	370	16.82	2.71	19.53	9.067	898	99	2.386	0.376	1,926	0.053
50	370	16.61	1.71	18.32	16.245	1,836	113	3.006	0.611	3,333	0.050
51	370	8.81	1.76	10.57	26.572	4,810	181	14.371	0.335	3,166	0.029
52	370	14.37	1.95	16.32	17.279	1,883	109	4.851	0.388	2,379	0.044
53	370	20.3	2.4	22.7	49.573	297	6	0.443	0.672	2,958	0.061
54	370	18.16	2.31	20.47	18.425	3,906	212	7.738	0.505	2,466	0.055
55	370	11.79	1.53	13.32	5.937	1,668	281	6.772	0.246	1,849	0.036
56	370	18.41	3.16	21.57	2.01	348	173	2.491	0.14	647	0.058
57	370	13.01	1.51	14.52	21.863	3,367	154	12.859	0.262	1,803	0.039
58	370	13.35	2.7	16.05	16.871	3,239	192	6.662	0.486	3,029	0.043
59	370	20.06	2.66	22.72	4.782	287	60	0.888	0.323	1,422	0.061
60	370	18.31	3.65	21.96	16.03	3,831	239	5.832	0.657	2,991	0.059
61	370	86.99	16.14	103.13	503.304	3,523	7	0.257	13.714	13,293	0.279
62	370	12.12	2.79	14.91	21.191	1,822	86	4.291	0.425	2,848	0.040
63	370	12.03	1.83	13.86	20.724	2,611	126	4.41	0.592	4,272	0.037
64	370	24.7	2.41	27.11	0.383	57	150	0.765	0.075	277	0.073
65	370	24.66	2.41	27.07	0.482	51	105	0.567	0.089	330	0.073
66	370	11.4	2.32	13.72	2.209	188	85	2.227	0.084	615	0.037
67	370	18.07	3.56	21.63	8.517	417	49	1.166	0.358	1,655	0.058
68	370	14.44	2.65	17.09	10.223	1,176	115	3.358	0.35	2,049	0.046
69	370	27.52	6.19	33.71	15.01	991	66	1.472	0.673	1,997	0.091
71	370	151.38	48.24	199.62	71.39	928	13	0.16	5.804	2,906	0.539

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Table 9. Summary of 100-Year Runoff and Erosion for the Walnut Creek Watershed, (continued)

HILLSLOPE	MEAN ANNUAL PRECIPITATION	MEAN ANNUAL RAIN RUNOFF	MEAN ANNUAL SNOW RUNOFF	MEAN ANNUAL RUNOFF	AVERAGE SEDIMENT YIELD	TOTAL SEDIMENT YIELD	HILLSLOPE WIDTH	HILLSLOPE AREA	AVERAGE ANNUAL SOIL LOSS	AVERAGE SUSPENDED SOLIDS	RUNOFF COEFFICIENT
	(mm)	(mm)	(mm)	(mm)	(kg/m)	(kg)	(m)	(hectares)	(tonnes/ha)	(mg/L)	
72	370	12.18	2.36	14.54	8.334	625	75	2.273	0.275	1,891	0.039
73	370	34.51	10.29	44.8	84.277	6,658	79	2.03	3.279	7,321	0.121
74	370	53.57	8.37	61.94	60.698	3,096	51	0.444	6.977	11,256	0.167
75	370	21.77	3.01	24.78	2.675	674	252	2.974	0.227	915	0.067
76	370	18.15	3	21.15	12.481	949	76	1.368	0.693	3,278	0.057
78	370	17.74	2.88	20.62	9.047	814	90	1.629	0.5	2,424	0.056
79	370	23.26	2.4	25.66	0.255	79	308	2.125	0.037	144	0.069
80	370	15.69	2.53	18.22	7.429	698	94	2.284	0.306	1,678	0.049
81	370	156.51	49.85	206.36	76.695	767	10	0.117	6.555	3,177	0.558
84	370	11.99	1.46	13.45	25.788	4,255	165	10.56	0.403	2,996	0.036
85	370	13.52	2.34	15.86	6.755	1,047	155	4.402	0.238	1,500	0.043
86	370	13.58	1.75	15.33	12.943	997	77	3.08	0.324	2,111	0.041
87	370	14.43	1.32	15.75	1.252	445	355	6.745	0.066	418	0.043
88	370	16.81	2.17	18.98	13.374	1,846	138	2.926	0.631	3,323	0.051
99	370	14.97	2.59	17.56	6.617	2,819	426	15.293	0.184	1,050	0.047

ESTIMATED ANNUAL WALNUT CREEK WATERSHED SEDIMENT YIELD (TONNES/HA)	0.324
ESTIMATED ANNUAL WALNUT CREEK WATERSHED SEDIMENT YIELD (TONS/ACRE)	0.144
ESTIMATED ANNUAL WALNUT CREEK WATERSHED EROSION DEPTH (mm)	0.036
ESTIMATED ANNUAL WALNUT CREEK RUNOFF COEFFICIENT	0.035

WALNUNT CREEK LAND USE	YIELDS (TONNES/HA)	SOLIDS (MG/L)	100-TEAR AVERAGE RUNOFF (MM)	COEFFICIENT	YIELD
IMPROVED ROADS	5.703	4,781	127	0.344	0.4%
HILLSLOPES WITH IMPROVED ROADS	0.859	3,366	20	0.053	29.2%
HILLSLOPES WITH UNIMPROVED ROADS	0.434	1,867	22	0.061	3.3%
HILLSLOPES WITH MINIMAL DISTUBANCE	0.217	1,411	16	0.044	66.4%

Table 10. Summary of Runoff and Sediment Yields for 100-Year Continuous WEPP Simulation and Six Design Storms for the South Interceptor Ditch Watershed

Event	100-Year Simulation Mean Annual		100-Year 6 Hour		10-Year 6 Hour		2-Year 6 Hour		2-Year 2 Hour		12-Year 11.5 Hour (5/17/95)		1-Year 11.5 Hour	
Rainfall			97.1 mm		62.3 mm		40.8 mm		31.5 mm		74.9 mm		35 mm	
	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield
Hillslope	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha
1	20.0	401.0	58.7	766.7	24.8	406.9	9.1	193.7	3.5	79.2	19.5	271.4	0.0	0.0
6	114.6	4,326	80.2	2,482	46.6	1,528	29.2	983.7	23.9	792.7	48.9	1,627	14.6	460.4
7	24.8	193.0	62.0	398.4	26.7	209.1	11.0	99.1	4.5	42.1	23.3	106.3	1.4	12.0
9	28.7	467.0	64.0	788.0	28.4	458.8	12.4	225.3	5.3	126.4	27.8	413.1	0.0	0.0
10	25.7	280.0	60.5	850.5	33.0	493.7	11.1	225.2	5.1	102.7	23.0	322.9	0.0	0.0
11	109.3	8,602	78.7	4,248	46.2	2,683	28.9	1,782	23.6	1,472	51.2	3,437	13.6	972.4
12	23.6	743.0	61.6	1,952	24.6	785.0	9.2	292.5	3.1	108.9	23.2	628.4	0.2	22.2
13	26.6	382.0	60.7	973.5	33.1	517.5	11.1	154.3	5.2	68.8	16.6	120.4	1.1	3.5
14	31.2	278.0	59.9	722.8	32.5	416.4	16.0	218.1	6.9	100.7	24.6	335.7	0.0	0.0
15	30.4	880.0	64.1	1,767	36.1	1,026	13.6	382.5	6.8	173.5	20.3	492.7	0.7	2.7
16	26.8	429.0	61.4	3,179	33.7	1,387	17.3	538.6	6.4	236.5	26.0	454.9	0.0	0.0
17	53.4	2,341	71.5	3,564	36.4	1,990	19.5	1,129	13.0	772.9	40.8	2,327	3.6	194.5
18	17.6	545.0	46.6	1,012	19.1	430.0	4.9	100.2	1.6	24.2	22.6	371.9	0.1	0.0
19	17.0	374.0	47.4	863.9	19.8	367.7	5.3	98.9	1.7	27.6	25.7	351.1	0.8	3.3
20	17.3	466.0	47.0	1,211	19.7	534.3	5.2	139.0	1.7	39.0	22.9	464.6	0.2	0.1
22	5.0	2.0	23.3	17.4	5.1	3.0	1.0	0.4	0.4	0.2	0.7	0.1	0.0	0.0
23	28.2	230.0	59.3	427.3	32.0	241.8	10.4	106.8	5.0	55.4	23.6	118.2	0.3	0.0
25	28.3	263.0	61.0	588.1	33.4	334.0	11.6	111.2	5.5	48.2	26.4	229.4	0.0	0.0
26	27.2	278.0	61.0	637.3	33.4	363.4	11.2	116.1	4.9	46.3	26.1	250.4	0.0	0.0
27	31.9	75.0	59.6	217.4	32.3	104.6	15.8	35.0	7.7	16.4	23.0	9.5	0.0	0.0

Table 11. Summary of Runoff and Sediment Yields for 100-Year Continuous WEPP Simulation and Six Design Storms for the Woman Creek Watershed

Event	100-year Simulation Mean Annual		100-Year 6 Hour		10-Year 6 Hour		2-Year 6 Hour		2-Year 2 Hour		12-Year 11.5 Hour (5/17/95)		1-Year 11.5 Hour	
Rainfall			97.1 mm		62.3 mm		40.8 mm		31.5 mm		74.9 mm		35 mm	
	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield
Hillslope	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha
1	10.0	234.0	26.8	862.9	5.7	161.9	0.7	10.3	0.3	3.9	22.7	242.6	0.8	1.8
2	12.9	442.6	36.6	1,091	12.1	309.9	1.2	25.4	0.5	9.8	9.8	44.4	1.6	3.7
3	16.6	614.1	40.2	1,545	14.9	444.7	1.7	41.9	0.8	17.0	19.0	156.4	2.4	5.5
4	4.6	83.8	21.6	431.3	4.4	76.7	0.5	6.9	0.3	3.4	0.0	0.0	0.0	0.0
5	4.7	76.7	22.8	442.0	4.7	72.2	0.5	5.9	0.3	2.9	0.0	0.0	0.0	0.0
6	15.9	111.0	39.4	379.8	14.3	143.5	1.4	17.3	0.6	7.2	16.1	25.2	2.3	0.3
7	26.1	127.8	41.8	545.9	15.9	207.1	2.7	0.9	7.9	15.0	20.6	9.5	7.0	0.6
8	21.9	126.6	61.4	332.8	24.0	146.3	8.6	57.5	2.9	22.2	20.3	90.6	1.4	0.1
9	19.0	307.1	43.4	627.1	16.3	249.1	3.5	37.4	1.2	12.4	17.6	133.6	5.0	4.2
10	117.0	5,361	83.8	4,113	48.3	2,274	30.7	1,371	25.7	1,104	48.9	1,782	14.4	455.2
11	106.2	3,998	83.5	3,346	47.7	1,875	30.5	1,009	25.5	810.7	48.2	1,407	13.6	379.0
12	101.4	5,848	83.2	5,629	47.5	3,166	30.3	1,752	25.3	1,403	48.0	2,136	13.5	455.3
13	111.6	4,491	83.5	3,441	47.8	2,012	30.5	1,127	25.6	906.4	48.2	1,540	13.6	395.3
14	18.6	273.4	41.7	714.4	14.7	311.0	3.0	80.2	1.0	25.1	9.2	198.8	1.2	2.7
15	14.6	204.6	15.9	354.7	3.2	68.5	0.4	4.2	0.2	1.2	23.3	325.0	7.0	74.1
16	24.2	28.6	11.3	25.5	2.3	3.4	0.3	0.2	0.2	0.0	15.4	15.6	6.4	4.9
17	30.0	248.8	57.8	530.9	22.1	221.0	6.6	12.9	2.1	4.0	19.0	32.8	7.5	3.0
18	20.1	243.9	43.1	717.3	15.8	264.5	3.5	55.2	1.0	13.6	13.6	142.3	0.8	0.1
19	15.2	54.4	26.0	157.2	5.5	28.4	0.5	0.4	0.2	0.2	13.8	4.1	4.6	0.2
20	76.6	2,826	83.0	2,053	43.2	1,212	25.6	726.3	21.1	601.2	47.9	1,347	13.6	404.3
21	95.1	8,453	83.4	4,803	47.7	2,936	30.4	1,993	25.4	1,716	48.1	3,374	13.6	1,038
22	12.6	110.9	29.0	394.1	6.5	100.0	0.6	6.6	0.3	2.0	15.2	59.5	4.0	2.1
23	34.8	411.4	59.6	579.3	32.3	270.3	10.2	95.3	4.3	39.3	32.1	132.1	5.4	7.1
24	106.9	5,133	83.3	2,979	47.6	1,916	30.3	1,206	25.4	994.5	48.1	1,944	13.4	552.3
25	16.2	537.7	41.4	1,099	14.1	405.8	2.9	71.8	0.9	18.7	12.2	333.7	0.2	1.3

Table 11. Summary of Runoff and Sediment Yields for 100-Year Continuous WEPP Simulation and Six Design Storms for the Woman Creek Watershed, (continued)

Event	100-year Simulation Mean Annual		100-Year 6 Hour		10-Year 6 Hour		2-Year 6 Hour		2-Year 2 Hour		12-Year 11.5 Hour (5/17/95)		1-Year 11.5 Hour	
Rainfall			97.1 mm		62.3 mm		40.8 mm		31.5 mm		74.9 mm		35 mm	
	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield
Hillslope	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha
26	23.8	83.2	58.6	279.6	23.6	107.4	8.1	10.8	2.7	1.7	20.2	2.8	2.8	0.3
27	15.9	573.1	39.3	1,161	13.4	365.7	1.9	35.7	0.6	10.3	2.4	45.0	0.1	0.0
28	26.2	202.1	28.1	501.1	5.9	70.1	8.1	16.6	6.7	9.8	16.7	7.1	5.7	1.1
29	46.7	138.0	50.3	348.4	24.6	98.4	12.0	13.5	9.9	11.2	24.5	11.2	8.1	2.3
30	26.7	128.6	59.5	227.8	32.2	105.8	10.2	20.8	4.3	11.0	21.1	2.8	0.0	0.0
31	18.5	297.0	47.8	664.4	20.7	246.2	5.7	62.5	1.9	18.9	18.6	109.2	0.0	0.0
32	15.2	157.2	35.1	474.5	8.9	170.2	1.9	30.3	0.5	7.7	12.0	151.9	0.1	0.0
33	14.9	195.3	34.5	629.9	9.2	183.3	2.2	12.9	0.7	1.4	21.9	235.2	2.2	0.2
34	8.6	228.5	13.8	263.1	2.5	42.2	0.1	1.0	1.2	28.9	16.9	185.8	1.0	13.9
35	14.0	151.8	28.2	255.4	6.9	27.0	2.8	3.6	1.2	2.7	27.0	105.3	1.2	0.7
36	17.2	79.7	42.6	272.6	14.9	57.1	3.4	2.0	1.0	0.8	16.8	3.1	4.8	0.4
37	16.7	35.3	42.4	99.4	14.7	16.3	3.3	1.6	1.0	0.6	12.8	2.3	1.6	0.2
38	18.5	46.6	50.0	142.1	22.3	29.4	7.1	4.1	2.1	1.2	24.3	7.6	0.7	0.1
39	11.5	47.7	29.5	105.1	6.6	11.8	0.9	0.6	0.4	0.3	23.1	8.0	3.5	0.2
40	34.0	214.5	59.5	399.4	32.2	216.8	10.6	63.8	4.9	27.2	23.3	121.9	0.0	0.0
41	13.7	77.8	39.0	307.6	11.8	54.9	2.6	1.3	0.8	0.5	15.8	29.1	0.0	0.0
42	11.7	11.2	27.9	58.4	5.4	4.5	2.5	1.4	2.0	0.6	5.3	0.7	1.7	0.2
43	13.5	189.5	35.8	516.0	9.8	126.4	2.3	23.4	0.7	4.3	18.3	242.2	2.8	1.7
44	13.1	179.9	32.6	551.4	8.5	66.1	0.6	2.9	0.3	1.0	9.2	1.7	1.3	0.1
45	19.5	79.8	50.6	241.2	22.8	83.5	7.5	11.4	2.3	1.8	26.8	37.1	1.5	0.2
46	15.4	483.6	34.7	1,017	9.0	283.2	1.9	47.5	0.6	12.4	9.6	221.2	0.8	13.2
47	29.7	113.0	59.5	342.9	24.3	161.7	8.9	14.9	3.2	5.6	21.4	8.3	6.4	0.5
48	20.1	38.8	51.0	127.7	23.4	28.0	8.1	3.6	2.5	1.4	23.7	4.2	0.0	0.0
49	105.2	7,775	83.8	4,904	48.3	2,847	30.7	1,829	25.7	1,517	48.9	2,883	14.4	869.0
50	17.4	205.9	36.5	644.9	11.8	183.1	0.9	7.3	0.4	2.1	2.5	9.5	1.0	2.1

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Table 12. Summary of Runoff and Sediment Yields for 100-Year Continuous WEPP Simulation and Six Design Storms for the Walnut Creek Watershed

Event	100-Year Simulation Mean Annual		100-Year 6 Hour		10-Year 6 Hour		2-Year 6 Hour		2-Year 2 Hour		12-Year 11.5 Hour (5/17/95)		1-Year 11.5 Hour	
Rainfall			97.1 mm		62.3 mm		40.8 mm		31.5 mm		74.9 mm		35 mm	
	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield
Hillslope	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha
1	14.1	246.0	37.1	791.6	11.3	275.4	1.8	26.6	0.6	11.0	20.9	250.1	1.5	0.4
2	14.2	146.7	36.8	466.9	11.6	166.5	1.3	15.2	0.6	5.9	14.9	86.4	2.9	1.6
3	15.2	257.1	41.6	736.0	14.3	297.2	2.9	57.7	0.8	16.4	14.3	327.3	0.4	0.0
4	4.5	86.9	8.9	224.0	1.8	47.8	0.2	4.2	0.1	1.5	4.1	78.1	0.5	0.0
5	14.4	101.5	37.9	432.0	12.3	112.9	1.3	2.3	1.9	6.3	18.6	75.2	1.4	0.0
6	11.4	418.4	29.4	673.2	6.6	166.2	0.6	12.4	0.2	5.7	13.5	162.7	1.9	2.5
7	121.2	7,869	83.2	1,883	47.5	1,223	30.2	717.6	25.3	578.3	47.9	1,025	13.3	249.9
8	106.0	7,587	82.2	1,656	46.5	1,012	29.3	655.4	24.3	546.9	47.0	1,083	12.4	271.9
9	17.6	184.3	38.8	602.4	12.4	205.7	2.0	21.9	0.6	7.8	26.9	182.4	1.6	0.2
10	11.2	194.8	31.8	489.1	7.7	102.5	1.7	16.5	0.5	4.5	31.6	335.6	0.9	0.1
11	18.5	288.8	46.5	713.6	19.4	311.2	4.9	65.6	1.6	16.8	20.6	291.4	0.0	0.0
12	21.2	219.1	58.2	646.8	21.3	260.7	6.4	67.5	2.1	19.7	25.3	207.6	0.4	0.1
13	10.1	173.3	15.0	302.1	2.7	44.2	0.2	0.5	0.0	0.0	20.8	83.4	1.1	0.5
14	101.3	4,419	83.3	3,133	47.6	1,919	30.3	1,146	25.4	933.3	48.1	1,694	13.5	456.7
15	6.3	203.9	14.3	418.5	2.8	78.4	0.3	7.1	0.1	3.3	11.0	100.7	0.1	0.4
16	22.9	23.4	59.2	134.1	23.7	30.6	8.5	4.4	3.0	1.9	22.5	4.6	0.0	0.0
17	9.1	71.6	22.2	275.0	3.4	33.0	0.0	0.0	0.0	0.0	8.2	0.1	1.0	0.1
18	18.3	34.4	45.2	153.8	18.0	33.7	4.1	2.4	1.2	0.9	22.9	5.6	1.4	0.1
19	8.2	26.9	19.6	118.3	2.7	4.3	1.5	0.3	1.0	0.2	17.5	0.1	0.6	0.0
20	10.1	11.1	17.6	48.0	2.7	2.3	4.1	1.3	2.2	0.5	17.4	0.2	1.7	0.1
21	4.8	18.0	6.1	26.7	0.8	0.7	0.8	0.2	0.4	0.1	1.6	0.1	0.3	0.0
22	11.5	264.7	34.0	840.4	9.2	234.9	1.5	36.7	0.5	14.3	18.8	180.5	1.7	31.2
23	15.4	11.9	43.1	58.1	15.7	14.0	3.4	1.8	1.1	0.7	22.4	4.6	0.0	0.0
24	13.6	568.9	39.7	1,282	12.5	496.9	2.9	128.9	0.9	42.1	12.5	439.8	0.2	1.6
25	17.9	344.4	42.1	876.5	15.5	349.5	3.0	58.9	1.0	19.5	27.2	463.5	5.5	60.5
26	15.4	443.5	43.4	871.5	16.2	387.5	3.7	101.4	1.2	33.0	11.8	244.8	0.2	0.2
27	13.1	314.8	41.9	749.4	14.5	229.4	3.1	37.1	0.9	9.2	28.4	399.6	0.1	0.2
28	8.7	74.3	21.6	240.1	4.2	17.4	0.3	0.1	2.0	1.2	16.6	33.2	0.5	0.0
29	13.8	550.5	37.3	941.2	11.1	317.2	1.9	44.0	0.7	16.1	24.0	401.5	2.1	15.2
30	15.7	224.8	38.8	608.4	12.4	211.1	2.2	25.6	0.8	8.0	26.1	335.9	5.6	45.2
31	61.3	506.0	80.7	207.1	37.5	105.0	19.7	35.1	15.5	22.4	45.5	81.9	5.4	5.0
32	9.3	68.1	21.7	272.5	3.3	27.6	0.0	0.0	1.4	0.3	17.7	0.1	1.0	0.0
33	16.5	308.0	44.2	820.2	17.5	365.3	3.8	80.0	1.3	24.2	19.5	309.2	0.3	0.0

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Table 12. Summary of Runoff and Sediment Yields for 100-Year Continuous WEPP Simulation and Six Design Storms for the Walnut Creek Watershed, (Continued)

Event	100-Year Simulation Mean Annual		100-Year 6 Hour		10-Year 6 Hour		2-Year 6 Hour		2-Year 2 Hour		12-Year 11.5 Hour (5/17/95)		1-Year 11.5 Hour	
Rainfall			97.1 mm		62.3 mm		40.8 mm		31.5 mm		74.9 mm		35 mm	
	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield
Hillslope	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha
34	15.7	241.9	43.5	772.8	16.7	298.0	3.4	54.1	1.1	17.5	20.3	212.2	0.4	0.0
35	20.3	500.2	46.9	829.1	19.8	373.1	5.2	96.1	1.6	31.5	23.2	369.5	0.4	0.0
36	19.3	441.9	49.3	720.6	21.6	374.2	6.3	142.1	1.9	48.5	26.1	406.4	1.9	0.0
37	17.5	131.1	45.4	417.5	18.1	142.9	4.3	15.0	1.4	1.6	22.7	116.2	0.0	0.0
38	17.9	78.4	44.7	252.7	17.2	49.3	8.4	3.5	2.5	1.5	28.9	10.6	7.3	0.4
39	13.7	417.8	40.7	1,039	13.5	366.1	2.6	59.4	0.8	16.1	24.5	494.1	0.0	0.0
40	9.8	199.2	30.4	658.4	7.0	163.5	1.4	27.5	0.5	7.7	17.9	200.0	1.4	25.7
41	222.8	4,142.0	93.6	1,256	58.8	590.4	34.6	264.4	29.5	223.2	68.0	361.8	27.6	133.4
42	16.8	479.6	43.3	752.6	16.3	197.3	3.3	43.8	1.1	14.0	24.5	220.1	2.2	17.5
43	24.6	98.8	59.6	191.2	32.3	90.2	15.6	24.6	6.5	17.6	21.5	3.3	1.0	0.0
44	12.7	398.3	32.8	938.0	8.2	256.3	1.7	45.0	0.6	15.5	20.4	170.4	2.6	59.6
45	16.6	520.2	47.5	874.1	20.2	365.1	5.4	81.8	1.7	19.9	22.2	262.7	0.1	0.4
46	19.7	706.5	44.3	964.6	16.9	419.9	3.8	87.9	1.1	25.7	30.8	598.9	0.8	16.1
47	20.6	350.7	46.8	926.7	19.6	405.8	5.0	102.7	1.7	32.6	29.6	389.8	2.2	33.2
48	21.8	174.3	46.0	506.2	19.0	227.2	4.7	34.1	1.6	10.9	29.4	174.5	6.0	0.6
49	19.5	376.2	48.1	874.3	20.9	414.8	5.9	127.3	1.9	34.8	19.1	296.5	4.1	23.4
50	18.3	610.7	47.6	922.3	20.2	397.2	5.5	126.5	1.6	41.0	23.2	360.8	1.0	0.1
51	10.6	334.7	29.8	1,046	6.6	269.8	1.3	53.6	0.4	17.8	7.0	167.4	2.2	1.0
52	16.3	388.3	45.4	935.9	17.9	356.1	4.3	66.6	1.3	17.0	14.9	267.1	0.8	1.8
53	22.7	671.4	47.3	437.7	19.2	153.1	4.8	35.0	1.5	9.6	11.3	81.8	0.0	0.0
54	20.5	504.8	47.1	1,028	19.8	524.1	5.2	183.6	1.6	62.7	22.2	514.6	2.3	16.0
55	13.3	246.3	34.9	807.3	10.7	309.5	0.8	48.8	0.3	15.8	16.0	17.0	1.5	0.1
56	21.6	139.6	56.0	382.8	20.9	158.6	5.9	24.6	2.1	6.9	22.7	58.9	3.3	0.3
57	14.5	261.8	41.5	537.4	13.8	205.6	3.2	47.9	0.9	13.2	11.2	138.8	2.9	1.6
58	16.1	486.2	39.2	757.1	13.0	266.2	2.1	31.4	0.7	10.1	19.8	242.1	2.1	1.8
59	22.7	323.1	47.4	416.6	20.1	174.4	5.2	23.0	4.7	29.6	30.5	62.8	1.8	10.5
60	22.0	656.9	46.5	812.6	19.4	309.9	4.5	74.6	1.4	24.3	17.9	172.6	0.7	3.4
61	103.1	13,708.7	83.4	2,950	47.7	1,812	30.4	1,239	25.5	1,077	48.1	2,064	13.6	630.2
62	14.9	424.7	38.4	770.9	11.6	252.5	2.2	27.8	0.7	7.0	27.3	404.8	2.0	1.4
63	13.9	592.1	36.4	798.3	11.1	265.3	1.2	27.6	0.6	12.6	13.1	196.1	1.8	12.6
64	27.1	75.0	58.2	171.2	31.1	76.9	14.5	16.9	6.2	5.9	17.5	3.1	0.0	0.0
65	27.1	89.3	58.2	199.1	31.1	93.5	14.5	24.4	6.2	8.7	17.5	3.7	0.0	0.0

Table 12. Summary of Runoff and Sediment Yields for 100-Year Continuous WEPP Simulation and Six Design Storms for the Walnut Creek Watershed, (Continued)

Event	100-Year Simulation Mean Annual		100-Year 6 Hour		10-Year 6 Hour		2-Year 6 Hour		2-Year 2 Hour		12-Year 11.5 Hour (5/17/95)		1-Year 11.5 Hour	
Rainfall			97.1 mm		62.3 mm		40.8 mm		31.5 mm		74.9 mm		35 mm	
	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield	Runoff	Sed Yield
Hillslope	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha	mm	kg/ha
66	13.7	84.3	35.2	290.9	10.2	64.2	0.9	0.3	0.4	0.1	17.4	2.5	1.1	0.1
67	21.6	357.9	45.6	816.9	19.0	402.4	4.5	80.7	1.6	28.7	27.1	383.6	5.3	47.0
68	17.1	350.1	41.3	1,156	15.1	447.5	2.7	68.6	1.0	30.9	23.0	337.8	4.5	34.9
69	33.7	673.0	62.5	2,000	25.7	706.9	10.0	189.7	3.7	55.8	18.5	306.2	2.9	27.1
71	199.6	5,800.4	92.1	1,527	57.3	829.7	33.1	403.0	28.1	338.0	66.6	559.2	26.2	141.8
72	14.5	275.0	38.5	705.4	12.9	268.2	1.7	28.2	0.7	12.5	19.8	274.0	3.3	25.4
73	44.8	3,279.7	61.5	2,758	24.9	908.3	9.4	243.5	3.4	76.7	26.5	697.6	4.2	71.3
74	61.9	6,972.1	60.4	2,920	32.9	1,418	16.5	628.9	8.1	312.5	22.5	853.8	6.6	231.9
75	24.8	226.7	54.6	566.9	28.4	322.2	5.7	64.9	2.4	29.1	20.9	142.5	4.1	11.1
76	21.2	693.4	54.6	749.6	18.1	253.9	3.0	40.2	1.4	19.5	15.8	131.5	2.8	22.5
78	20.6	499.8	55.8	645.4	18.9	231.0	4.1	43.1	1.6	18.4	20.7	119.2	3.1	12.9
79	25.7	37.0	58.2	84.2	31.1	37.7	14.5	9.9	5.4	3.6	17.5	3.2	0.0	0.0
80	18.2	305.8	44.9	797.7	18.3	352.7	4.1	61.6	1.4	23.7	23.1	258.6	0.8	0.2
81	206.4	6,555.2	92.6	1,519	57.8	859.6	33.6	433.6	28.5	367.6	67.0	644.3	26.7	191.3
84	13.5	402.9	37.9	1,108	10.9	279.6	2.3	43.3	0.7	10.8	29.6	664.2	0.1	0.4
85	15.9	237.9	40.8	729.4	14.8	292.2	2.5	44.0	0.9	18.5	21.8	199.5	3.7	1.3
86	15.3	323.6	40.8	534.9	13.2	196.7	2.9	41.9	0.9	12.0	14.4	79.9	0.1	0.4
87	15.8	65.9	45.6	386.7	18.5	138.6	4.5	17.7	1.4	2.5	22.7	123.1	0.0	0.0
88	19.0	630.8	45.7	818.8	18.9	384.4	4.4	75.4	1.5	33.6	13.9	50.6	1.8	9.3
99	17.6	184.3	54.4	1,795	26.6	709.1	10.8	264.9	3.9	107.2	19.2	382.5	4.9	85.2

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Table 13. Comparison of HEC-6T Modeling Results for Site Watersheds

COMPARISON OF HEC6T MODEL RESULTS FOR WOMAN CREEK

EVENT RETURN PERIOD / PROBILITY (YRS) / %	DURATION (HRS)	RAIN (mm)	HEC-6T RUNOFF (mm)	HEC-6T PEAK Q (mm/hr)	MASTER PLAN* RUNOFF (mm)	MASTER PLAN* PEAK Q (mm/hr)	HEC-6T TOTAL QS (Kg)	ESTIMATED DEPOSITION (%)	ESTIMATED Pu CONCENTRATION (pCi/L)	ESTIMATED Am CONCENTRATION (pCi/L)	ESTIMATED TSS CONCENTRATION (mg/L)
2 / 50	2	31.5	1.12	1.64		-	1,062	76	1.91	0.137	214
1 / 100	11.5	35	2.51	1.00		-	249	91	0.047	0.006	22
2 / 50	6	40.8	2.34	2.21	2.51	0.67	1,745	81	1.06	0.138	168
10 / 10	6	62.3	10.72	7.81	21.71	8.52	20,404	68	1.36	0.188	430
15 / 7	11.5	74.9	16.03	4.45	***42.03***	***3.27***	15,677	68	1.56	0.076	221
100 / 1	6	97.1	32.85	18.64	83.79	36.86	92,196	59	1.882	0.253	633

Master Plan Drainage Area: 554 Ha
WEPP/HEC-6T Drainage Area: 443 Ha

COMPARISON OF HEC6T MODEL RESULTS FOR MOWER DITCH

EVENT RETURN PERIOD / PROBILITY (YRS) / %	DURATION (HRS)	RAIN (mm)	HEC-6T RUNOFF (mm)	HEC-6T PEAK Q (mm/hr)	*MEASURED* RUNOFF (mm)	*MEASURED* PEAK Q (mm/hr)	HEC-6T TOTAL QS (Kg)	ESTIMATED DEPOSITION (%)	ESTIMATED Pu CONCENTRATION (pCi/L)	ESTIMATED Am CONCENTRATION (pCi/L)	ESTIMATED TSS CONCENTRATION (mg/L)
2 / 50	2	31.5	1.10	1.75			76.2	59	0.52	0.09	97
1 / 100	11.5	35	1.31	0.52			1.5	84	0	0	2
2 / 50	6	40.8	3.34	2.68			333	57	1.43	0.263	140
10 / 10	6	62.3	7.08	6.36			4,904	45	5.6	1.02	972
15 / 7	11.5	74.9	19.05	3.70	***30.13***	***2.52***	5,216	46	3.88	0.66	384
100 / 1	6	97.1	38.62	13.10			18,952	42	5.89	1.05	689

WEPP/HEC-6T Drainage Area: 71 Ha

*Values from: EG&G, 1992, Rocky Flats Plant Drainage and Flood Control Master Plan (Prepared by Wright Water Engineers, Inc.)
Bold Italics = Estimated from USGS Mean Daily Discharge Data (USGS, 1996)

COMPARISON OF HEC-6T MODEL RESULTS FOR THE SID

EVENT RETURN PERIOD / PROBILITY (YRS) / %	DURATION (HRS)	RAIN (mm)	HEC-6T RUNOFF (mm)	HEC-6T PEAK Q (mm/hr)	MASTER PLAN RUNOFF (mm)	MASTER PLAN PEAK Q (mm/hr)	HEC-6T TOTAL QS (Kg)	ESTIMATED DEPOSITION (%)	ESTIMATED Pu CONCENTRATION (pCi/L)	ESTIMATED Am CONCENTRATION (pCi/L)	ESTIMATED TSS CONCENTRATION (mg/L)
2 / 50	2	31.5	6.3	6.69	-	-	1453	70	12.89	2.03	317
1 / 100	11.5	35	4.8	0.93	-	-	8.42	99	0.159	0.025	2
2 / 50	6	40.8	11.0	8.36	3	0.84	3,552	68	14.0	2.00	440
10 / 10	6	62.3	26.5	19.51	15	9.20	10,901	54	31.9	4.55	562
15 / 7	11.5	74.9	25.3	6.83	***21***	***2.29***	6,871	65	14.87	2.093	370
100 / 1	6	97.1	52.6	43.20	42	30.66	35,237	43	32.8	4.66	915

Bold Italics = SW027 Estimated Data
Master Plan Drainage Area: 63.3 Ha
WEPP/HEC-6T Drainage Area: 74.4 Ha

COMPARISON OF HEC6T MODEL RESULTS FOR WALNUT CREEK

EVENT RETURN PERIOD / PROBILITY (YRS) / %	DURATION (HRS)	RAIN (mm)	HEC-6T RUNOFF (mm)	HEC-6T PEAK Q (mm/hr)	MASTER PLAN* RUNOFF (mm)	MASTER PLAN* PEAK Q (mm/hr)	HEC-6T TOTAL QS (Kg)	ESTIMATED DEPOSITION (%)	ESTIMATED Pu CONCENTRATION (pCi/L)	ESTIMATED Am CONCENTRATION (pCi/L)	ESTIMATED TSS CONCENTRATION (mg/L)
2 / 50	2	31.5	9.90	9.81			1,720	80	0.013	0.007	40
1 / 100	11.5	35	4.29	2.87			451	89	0.029	0.007	24
2 / 50	6	40.8	13.57	5.12	5.39	2.23	4,756	77	0.023	0.009	81
10 / 10	6	62.3	30.82	12.60	15.15	8.50	39,982	57	0.086	0.028	301
15 / 7	11.5	74.9	25.30	6.23	15.28	1.28	34,372	61	0.073	0.021	315
100 / 1	6	97.1	65.51	27.83	38.01	24.44	132,007	48	0.126	0.04	467

*Values from: EG&G, 1992, Rocky Flats Plant Drainage and Flood Control Master Plan (Prepared by Wright Water Engineers, Inc.)
Bold Italics = Estimated from USGS Mean Daily Discharge Data (USGS, 1996)
Master Plan Drainage Area: 961 Ha
WEPP/HEC-6T Drainage Area: 431 Ha

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Table 14. Summary of Actinide Transport Model Results for Each Watershed, Locations, and Probabilities of Surface Water Concentrations Above 0.15pCi/L for Pu and Am

WATERSHED	STORM PRECIPITATION DEPTH (mm)	STORM DURATION (hrs)	STORM EVENT RETURN PERIOD (Yrs)	ANNUAL PROBABILITY OF OCCURRENCE (%)	ACTINIDE TRANSPORT MODEL PREDICTS GREATER THAN 0.15 pCi/L Pu OR Am IN STREAM REACH						
					UPSTREAM OF 903 PAD	DOWNSTREAM OF 903 PAD					
	31.5	2	2	50%	Not	X					
	35	11.5	1	100%	> 0.15 pCi/L						
	40.8	6	2	50%	Upstream	X					
SID	62.3	6	10	10%	from	X					
	74.9	11.5	15	7%	903	X					
	97.1	6	100	1%	Pad	X					
					N. WOMAN CR.	S. WOMAN CR.	CONFLUENCE N. & S. WOMAN TO POND C-1	SMART DITCH OVERFLOW TO WOMAN	POND C-1 TO MOWER DIVERSION	MOWER DIVERSION TO SMART DITCH OVERFLOW	SMART DITCH CONFLUENCE TO INDIANA ST.
	31.5	2	2	50%		Not	X	X	X	X	X
	35	11.5	1	100%		> 0.15 pCi/L		X			
	40.8	6	2	50%	X	In	X	X	X	X	X
WOMAN CREEK	62.3	6	10	10%	X	South	X	X	X	X	X
	74.9	11.5	15	7%	X	Woman	X	X	X	X	·X
	97.1	6	100	1%	X	Creek	X	X	X	X	X
					MOWER DIVERSION TO INDIANA STREET						
	31.5	2	2	50%	X						
	35	11.5	1	100%							
	40.8	6	2	50%	X						
MOWER DITCH	62.3	6	10	10%	X						
	74.9	11.5	15	7%	X						
	97.1	6	100	1%	X						
					NORTH WALNUT FROM HEAD TO NO NAME GULCH	SOUTH WALNUT FROM INUSTRIAL AREA TO N. WALNUT	NO NAME GULCH	McKAY DITCH	A-SERIES PONDS	B-SERIES PONDS	NO NAME GULCH TO INDIANA ST.
	31.5	2	2	50%	X			Not	X	X	Not
	35	11.5	1	100%	X		X	> 0.15 pCi/L			> 0.15 pCi/L
	40.8	6	2	50%	X		X	In	X	X	at
WALNUT CREEK	62.3	6	10	10%	X	X	X	McKAY	X	X	Indiana
	74.9	11.5	15	7%		X		Ditch	X	X	Street
	97.1	6	100	1%	X	X	X		X	X	

Table 15. Surface Water Samples with Pu > 0.15 pCi/L at Gaging Stations GS03 and SW027

Gaging Station	Sample Date/ Composite Duration	Pu Result (pCi/L)	Am Result (pCi/L)	TSS (mg/L)*	Event Type	Comment
GS03	4/9/97-4/15/97	0.220	0.059		Pond A-4 Discharge	7.4 mm of precipitation recorded during composite period.
	6/25/97-6/27/97	0.165	0.018		Pond A-4 Discharge	3.8 mm of precipitation recorded during composite period.
	6/27/97-7/1/97	0.184	0.056		Pond A-4 Discharge	0.5 mm of precipitation recorded during composite period.
SW027	6/22/89	0.820	0.140	54	Baseflow	No associated precipitation event.
	6/11/90	0.317	0.088	82	Baseflow	No associated precipitation event.
	7/18/90	0.266	0.062	79	Baseflow	No associated precipitation event.
	12/6/90	0.362	0.074		Baseflow	No associated precipitation event.
	5/17/95	0.267	0.119	77	Precipitation (74.9 mm)	12.7 mm of precipitation on previous day.
	5/27/95	2.136	0.374	98	Precipitation (8.1 mm)	Rain previous seven days.
	6/28/95	2.289	0.300	74	Precipitation (11.4 mm)	Isolated Precipitation event.
	4/20/98-4/30/98	0.204	0.016		Precipitation (Total = 20.3 mm)	Rain occurred 3 of 11 days during composite collection. Light rain 7 consecutive days prior to sample start.
	4/30/98-5/8/98	0.802	0.124		Precipitation (Total = 31.0 mm)	Rain occurred 5 of 9 days during composite collection.
	5/8/98-5/26/98	0.333	0.106		Precipitation (Total = 33.8 mm)	Rain occurred 5 of 19 days during composite collection. Rain 4 consecutive days prior to sample start.
	4/30/99-5/1/99	0.190	0.027	13	Precipitation (Total = 27.4 mm)	Rain occurred 2 of 2 days during composite collection. Rain 2 consecutive days prior to sample start totaling 19.6 mm

* TSS available only when sample duration does not exceed 7-day hold time.

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FIGURES

Figure 2. RFETS Monthly Mean Precipitation, 1993 – 1999

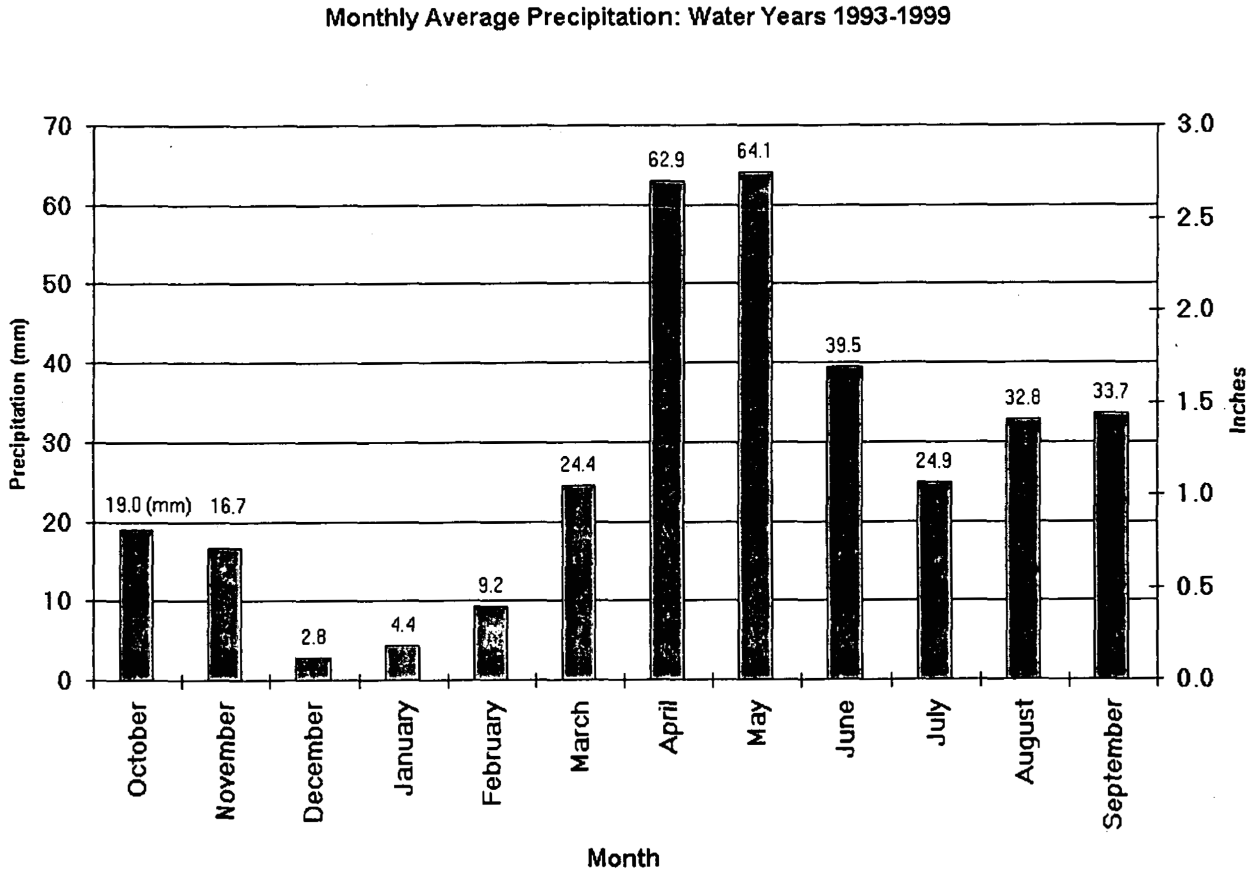

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Figure 3. Protocol for WEPP Erosion Modeling, HEC6-T Sediment Transport Modeling, and Estimation of Surface Water Concentrations of Pu and Am

IDENTIFY DRAINAGE PROFILES (HILLSLOPES)

↓

IDENTIFY VEGETATION AND SOIL TYPES AND CHARACTERISTICS

↓

DELINEATE OVERLAND FLOW ELEMENTS (OFEs)

↓

DETERMINE DIMENSIONS AND SLOPES FOR HILLSLOPES AND OFEs

↓

DETERMINE PLANT AND SOIL PARAMETERS USING MEASURED DATA

↓

CALIBRATE PLANT PARAMETERS TO SIMULATE OBSERVED GROWTH, COVER, AND RESIDUE CHARACTERISTICS

↓

CALIBRATE SOIL PARAMETERS TO SIMULATE OBSERVED RUNOFF CHARACTERISTICS

↓

CALIBRATE SOIL PARAMETERS TO OBSERVED EROSION DATA

↓

COMPILE EROSION MODEL OUTPUT AND FORMAT FOR GEOGRAPHIC INFORMATION SYSTEM (GIS) MAPPING

↓

MAP EROSION DATA, COMBINE WITH SOIL DISTRIBUTIONS OF PU AND AM TO ESTIMATE YIELDS TO SURFACE WATER

↓

TRANSFORM EROSION MODEL SEDIMENT PARTICLE SIZE ESTIMATES FOR SEDIMENT TRANSPORT MODELING USING WATER-STABLE AGGREGATE DISTRIBUTION FOR SITE SOILS

↓

PREPARE RUNOFF AND SEDIMENT HYDRDOGRAPHS FROM EROSION MODEL OUTPUT AND FORMAT FOR SEDIMENT TRANSPORT MODEL

↓

CALIBRATE SEDIMENT TRANSPORT MODEL TO MEASURED DATA FROM STREAM GAGES

↓

CALCULATE ENRICHMENT FACTORS FOR PU AND AM TRANSPORTED WITH EROSION SEDIMENT USING WATER-STABLE AGGREGATE DISTRIBUTION FOR SITE SOILS

↓

EXTRACT FLOW AND SEDIMENT OUTPUT FROM TRANSPORT MODEL, POPULATE SURFACE WATER CONCENTRATION CALCULATOR TO ESTIMATE SEDIMENT AND PU AND AM CONCENTRATIONS IN DRAINAGES

↓

POPULATE SURFACE CLEANUP LEVEL CALCULATOR WITH HILLSLOPE SEDIMENT AND PU AND AM YIELDS CLEANUP TO SELECTED LEVEL AND ESTIMATE POST CLEANUP PU AND AM CONCENTRATIONS IN DRAINAGES USING THE CONCENTRATION CALCULATOR

Figure 10. Distribution of Precipitation for 6-Hour Design Storms for the Rocky Flats Environmental Technology Site

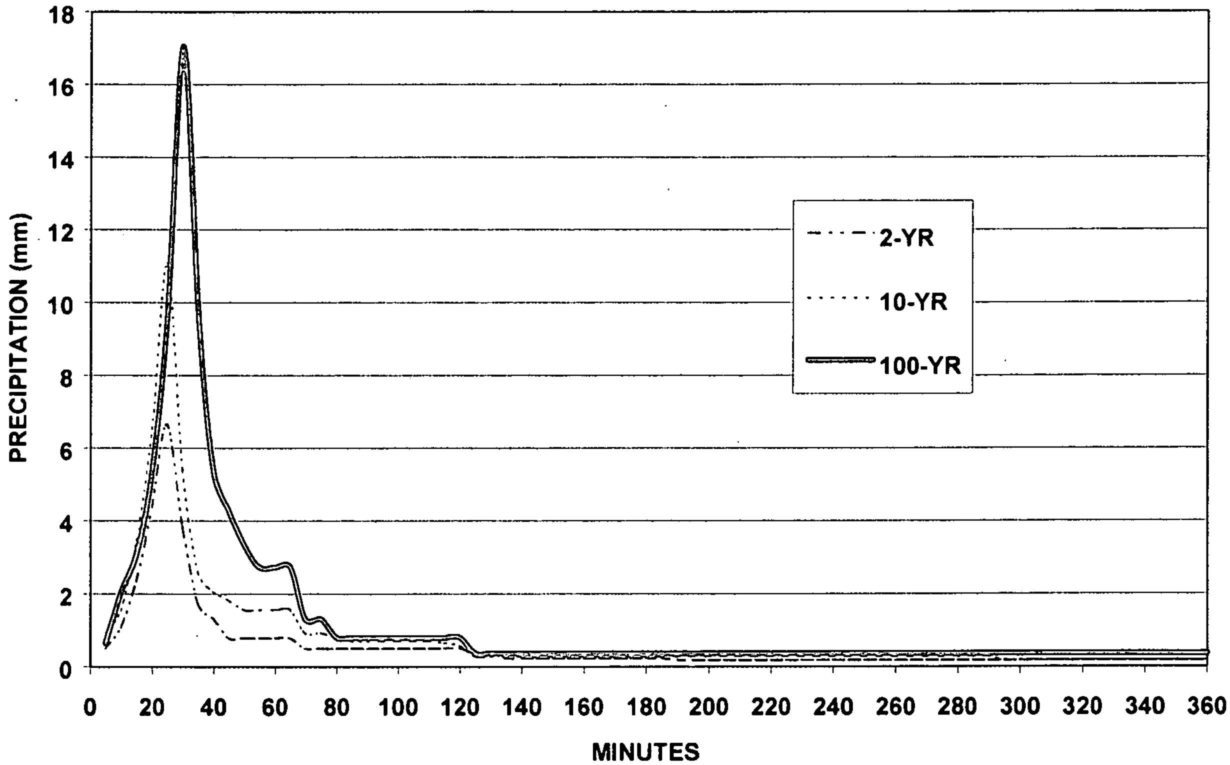

Figure 14. (a) Annual Erosion Rates for the 100-Year Simulation for the South Interceptor Ditch Watershed

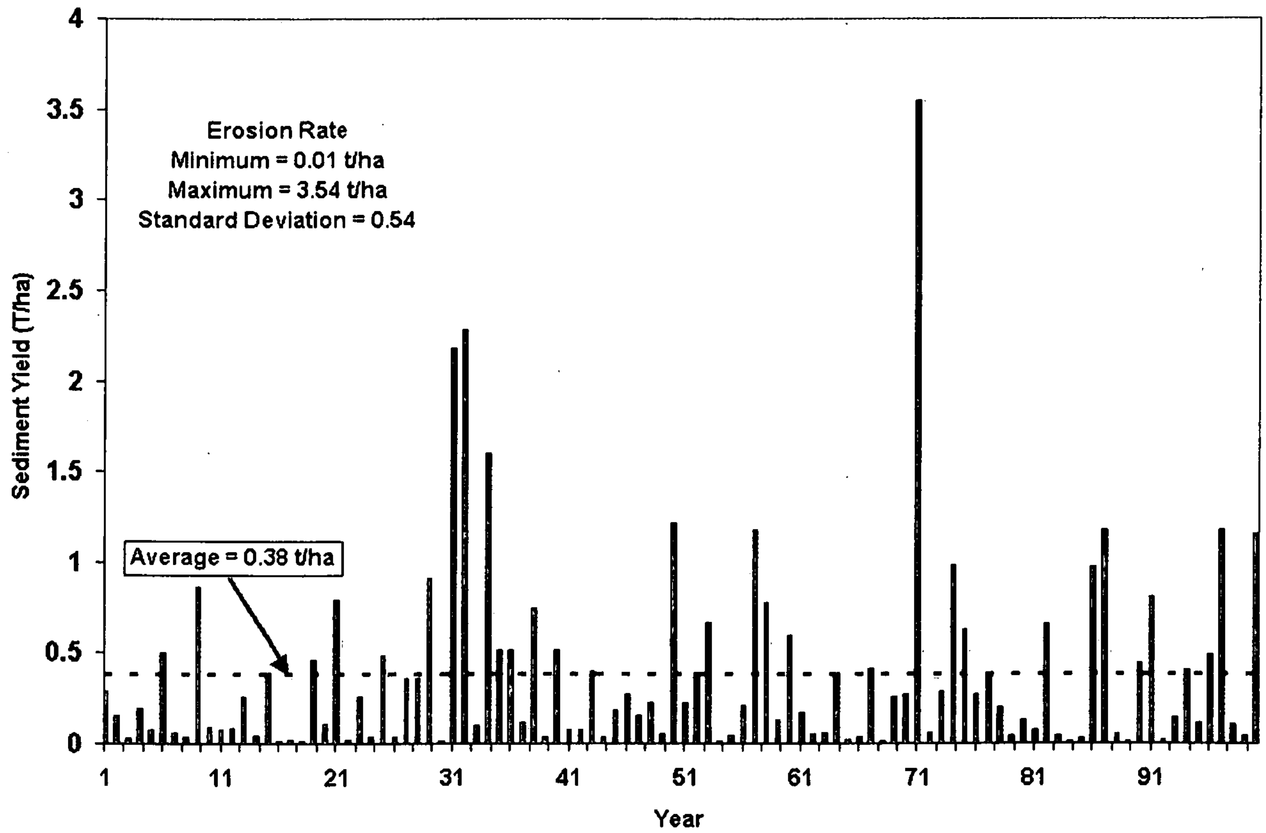

Figure 14. (b)Comparison of Erosion Rates for 100-Year Annual Average and Design Storms for Hillslopes in the South Interceptor Ditch Watershed

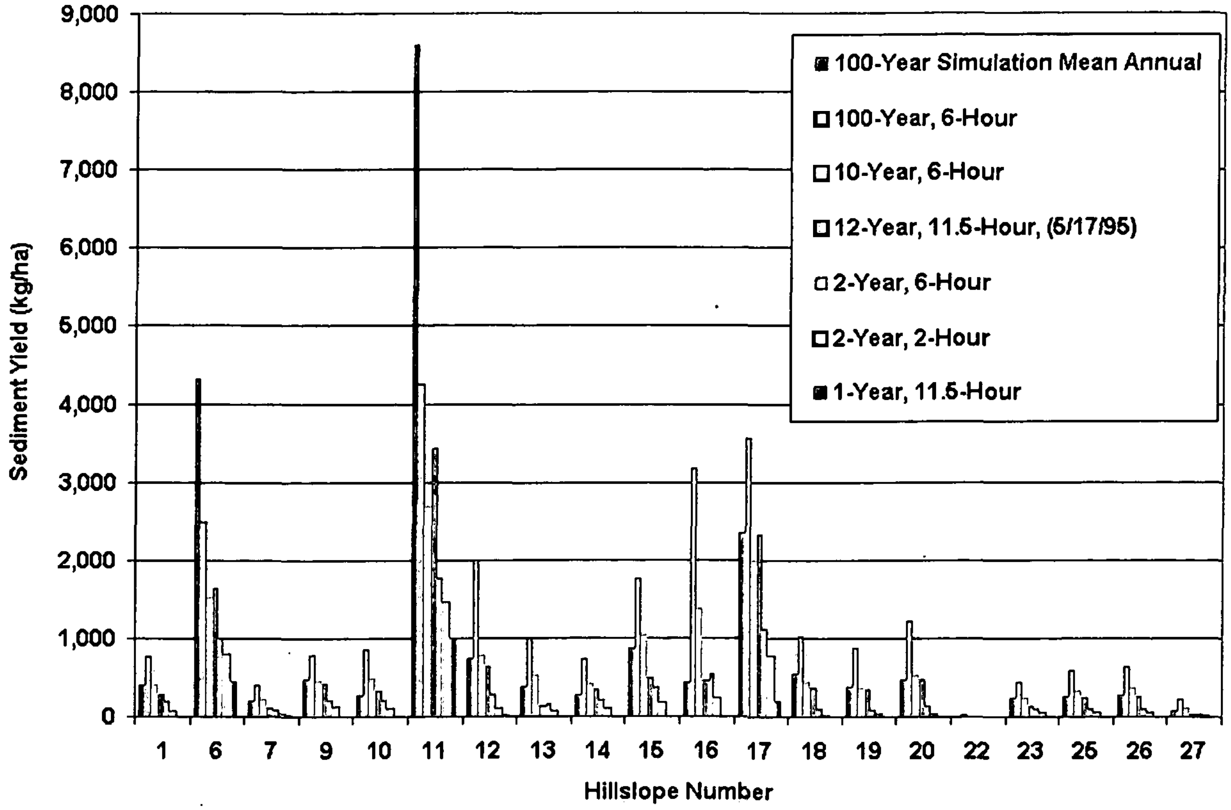

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Figure 15. Compiled Runoff Relationships for Different Hillslope Disturbance Types in the South Interceptor Ditch Watershed (a) Rainfall versus Runoff

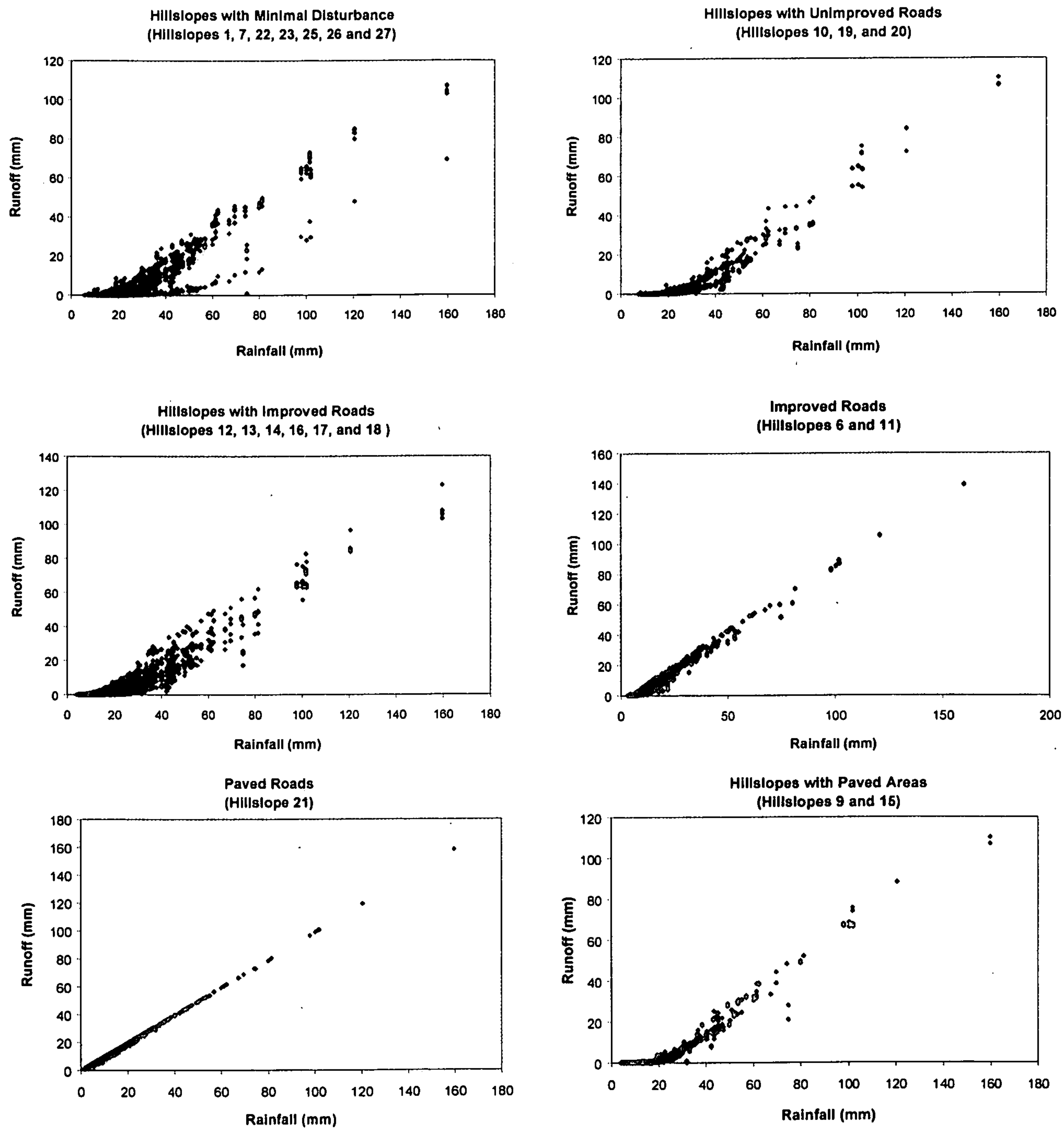


Figure 15 continued (b) Rainfall versus Sediment Yield

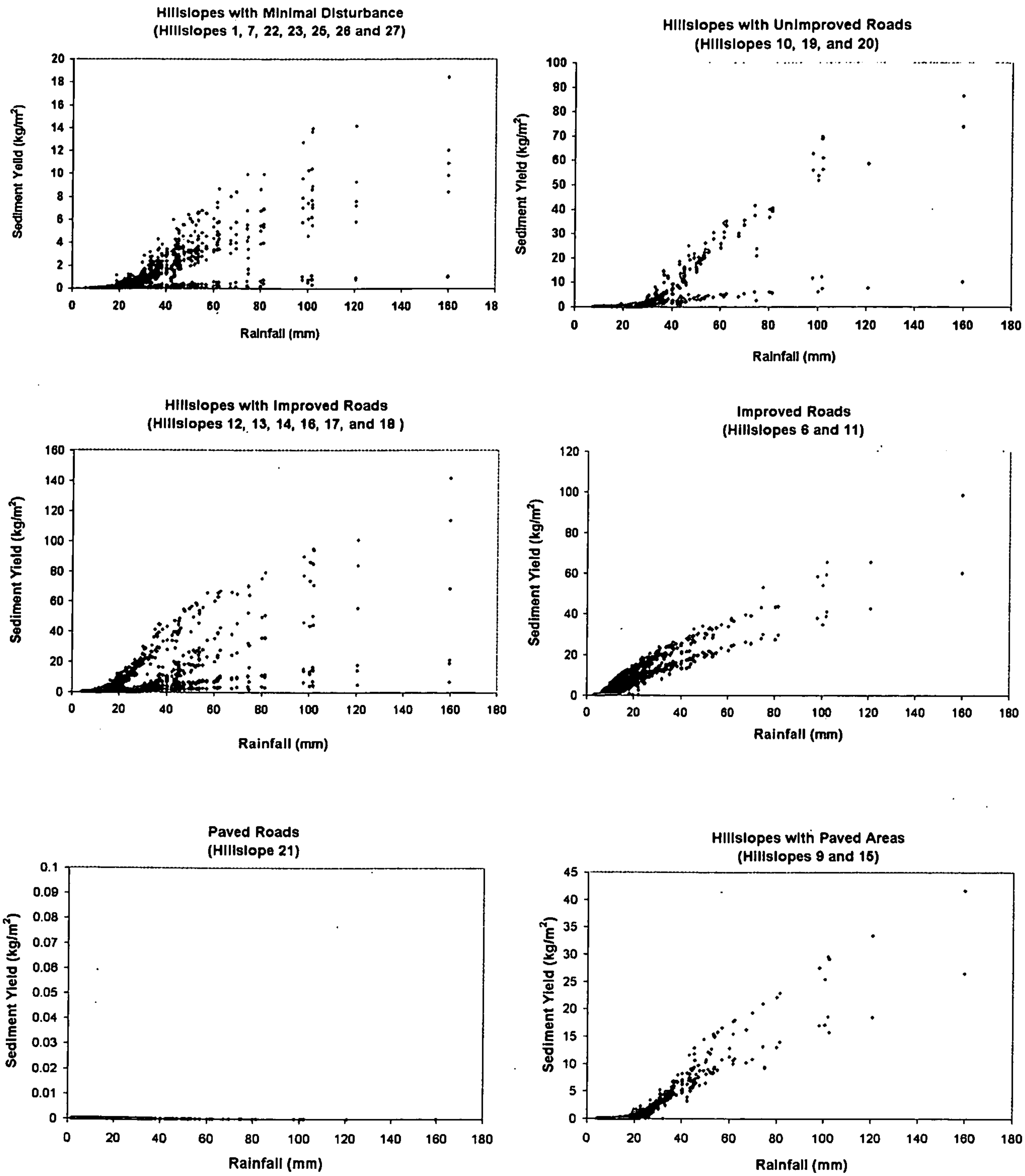
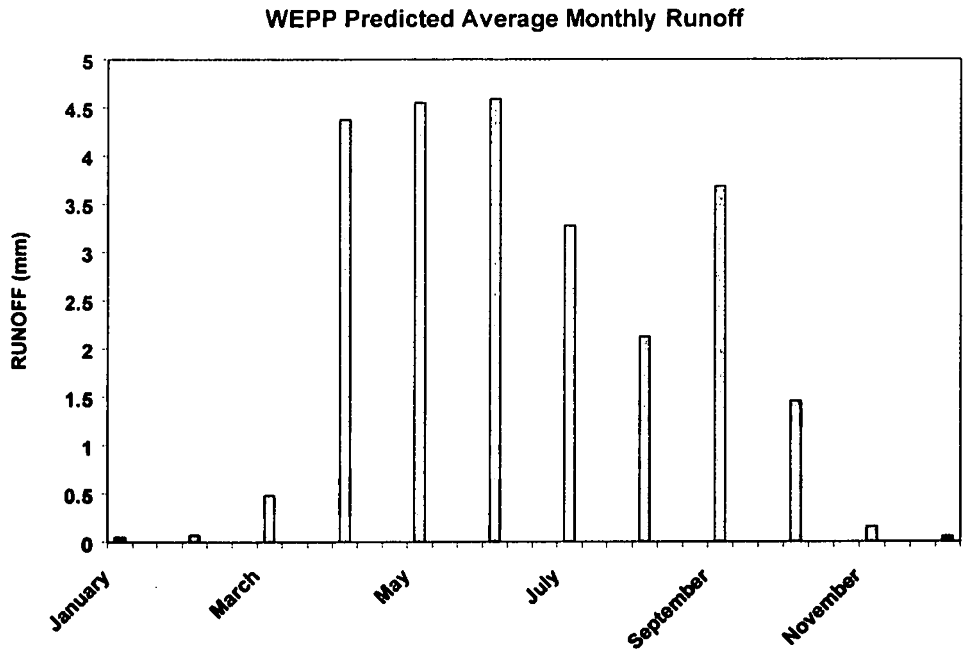


Figure 16. Comparison of WEPP-Predicted Average Monthly Runoff and Erosion Rates in the South Interceptor Ditch Watershed



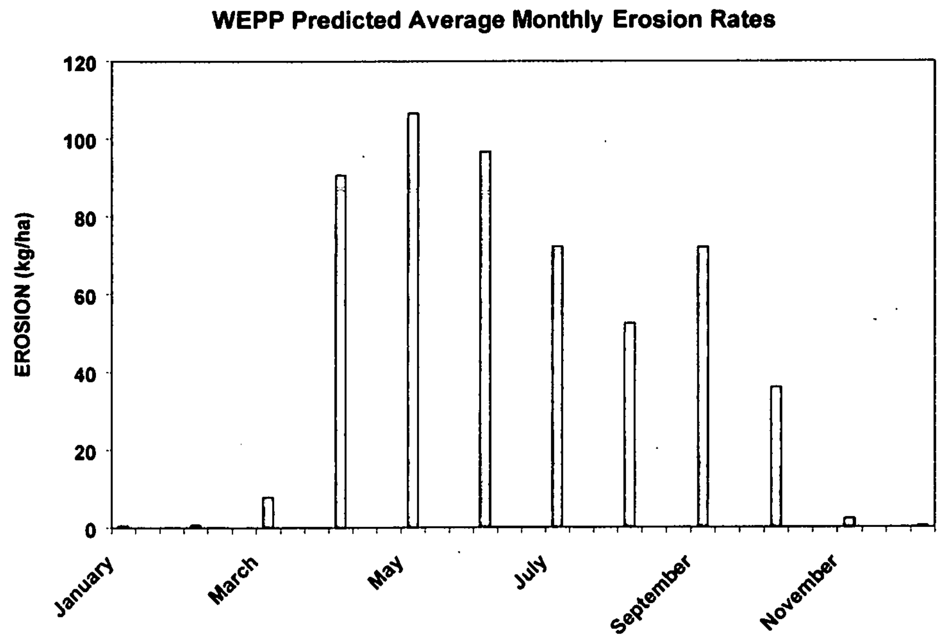


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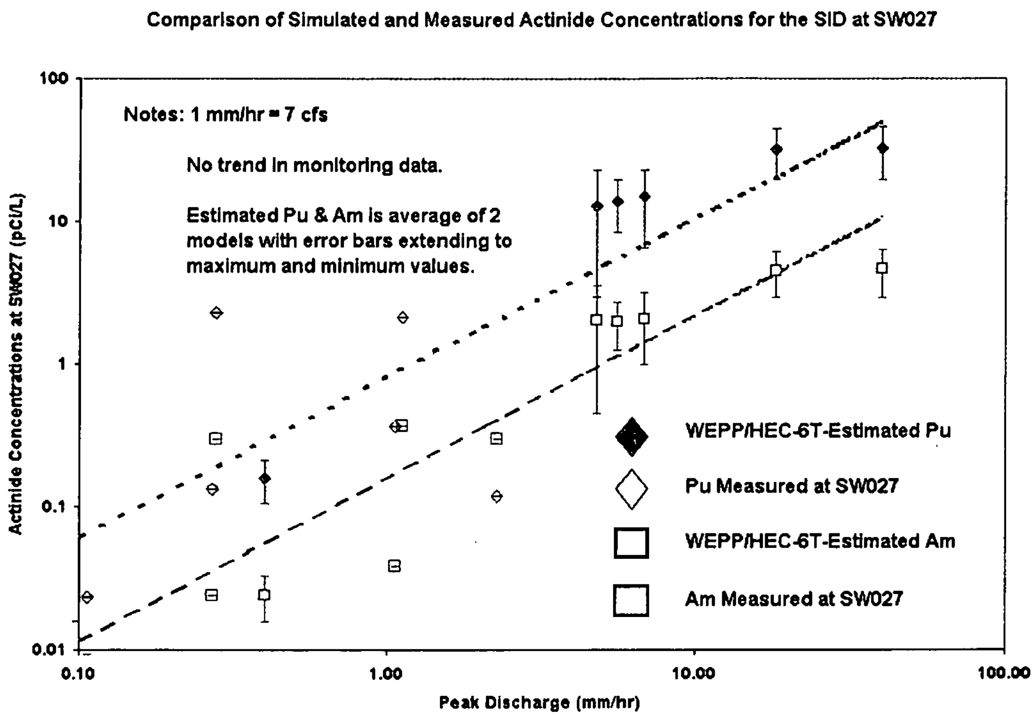
Figure 43. Measured and Simulated Actinide Concentrations for Evaluation of the HEC-6T Models – SID and Walnut Creek Watersheds (a)



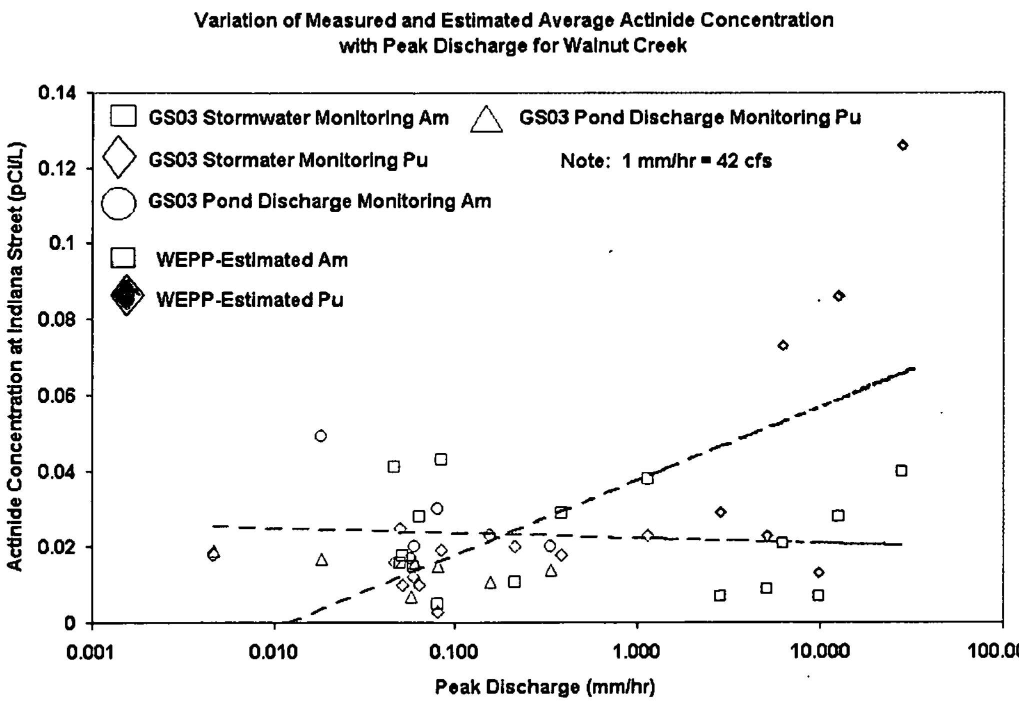
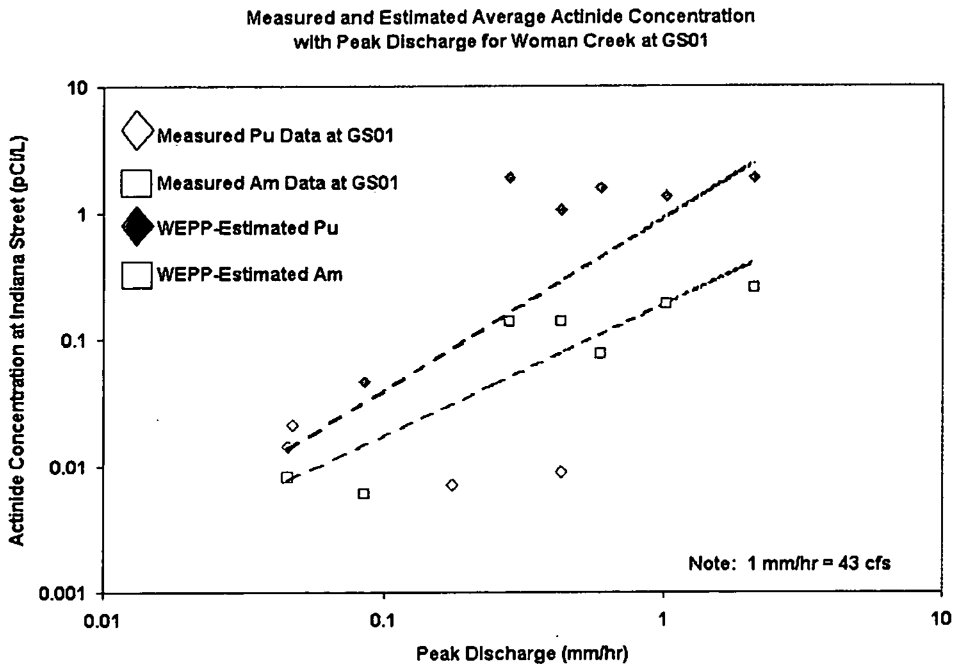
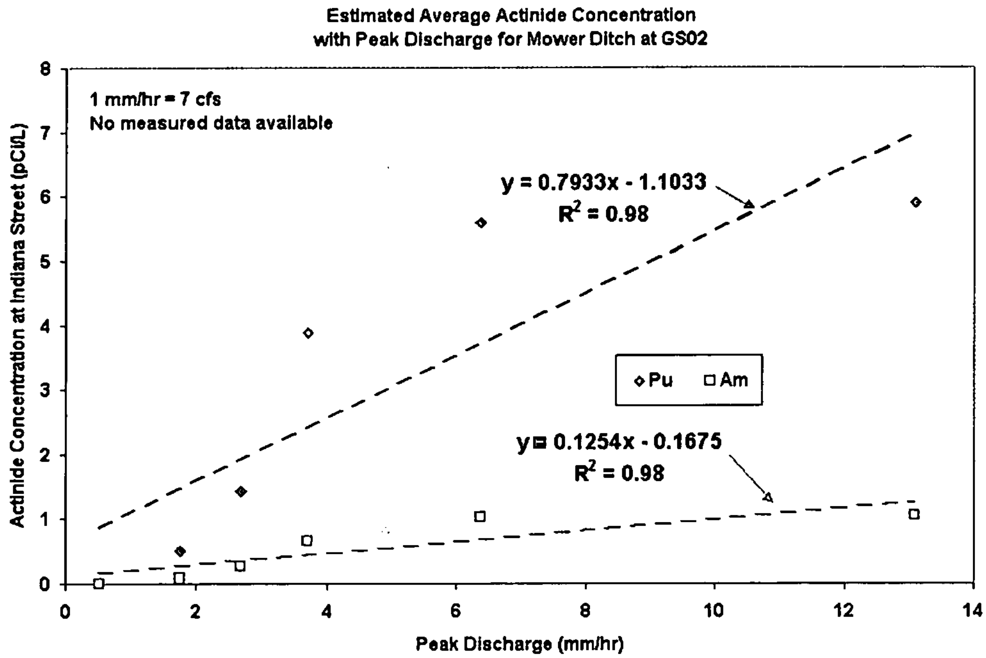


Figure 43. Measured and Simulated Actinide Concentrations for Evaluation of the HEC-6T Models – Woman Creek and Mower Ditch Watersheds (b)





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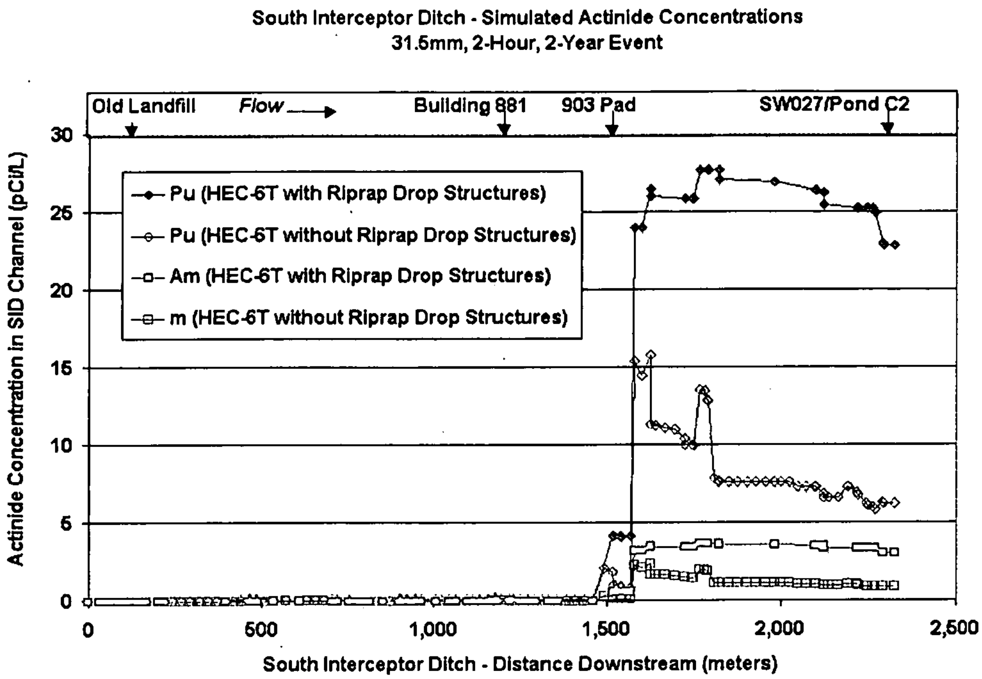

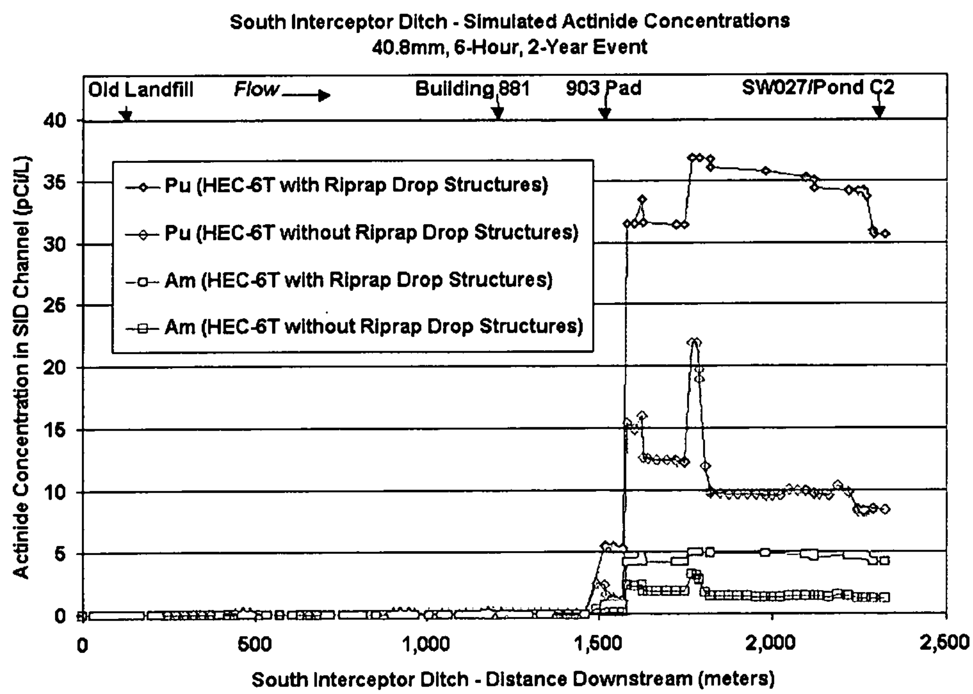

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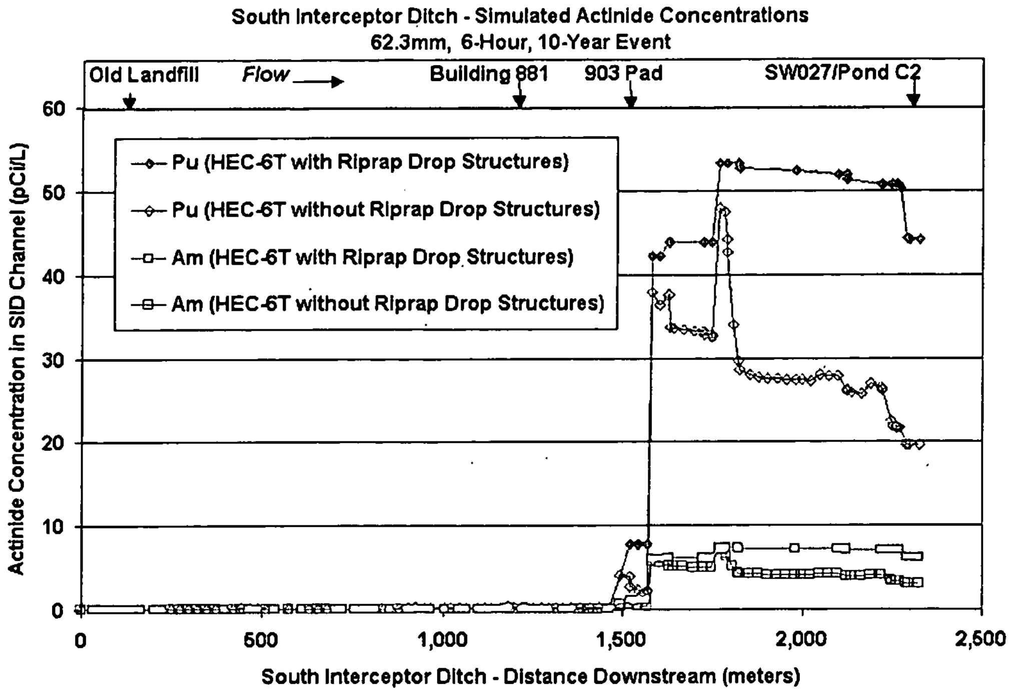

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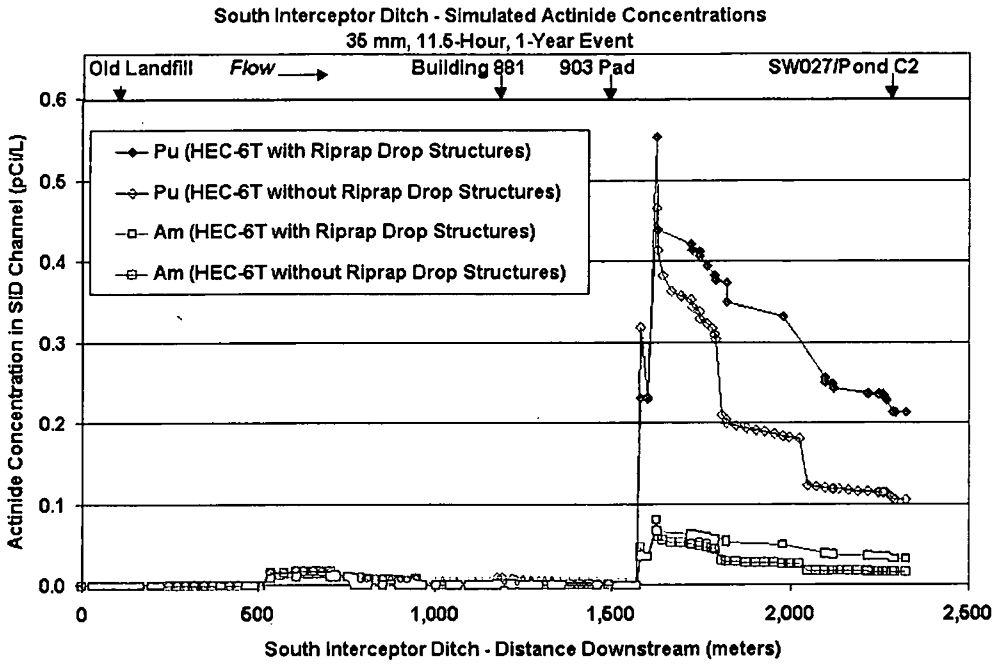

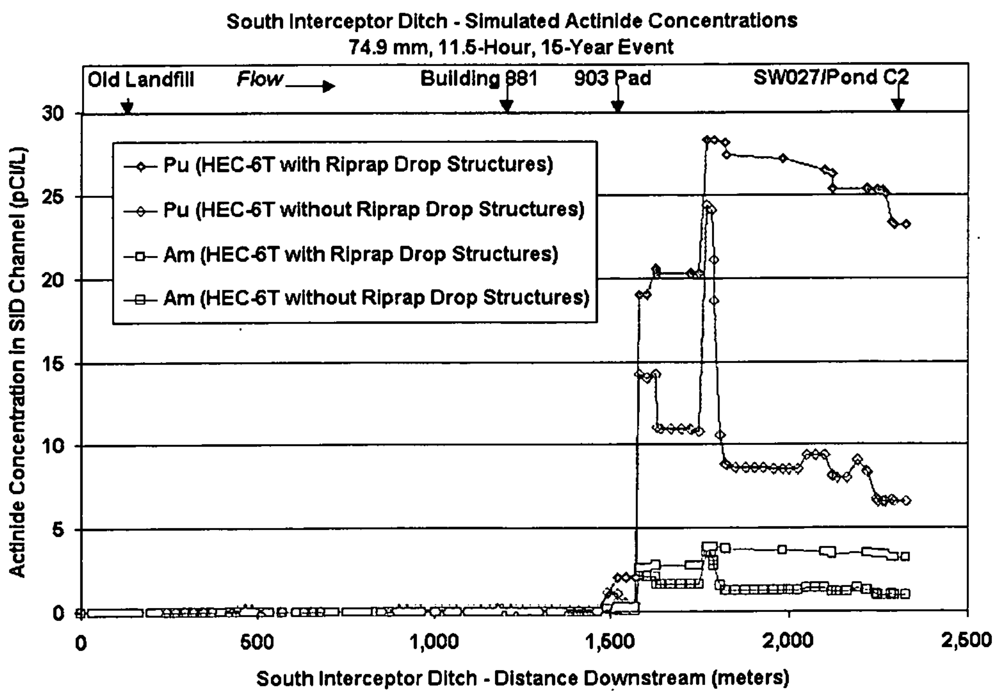

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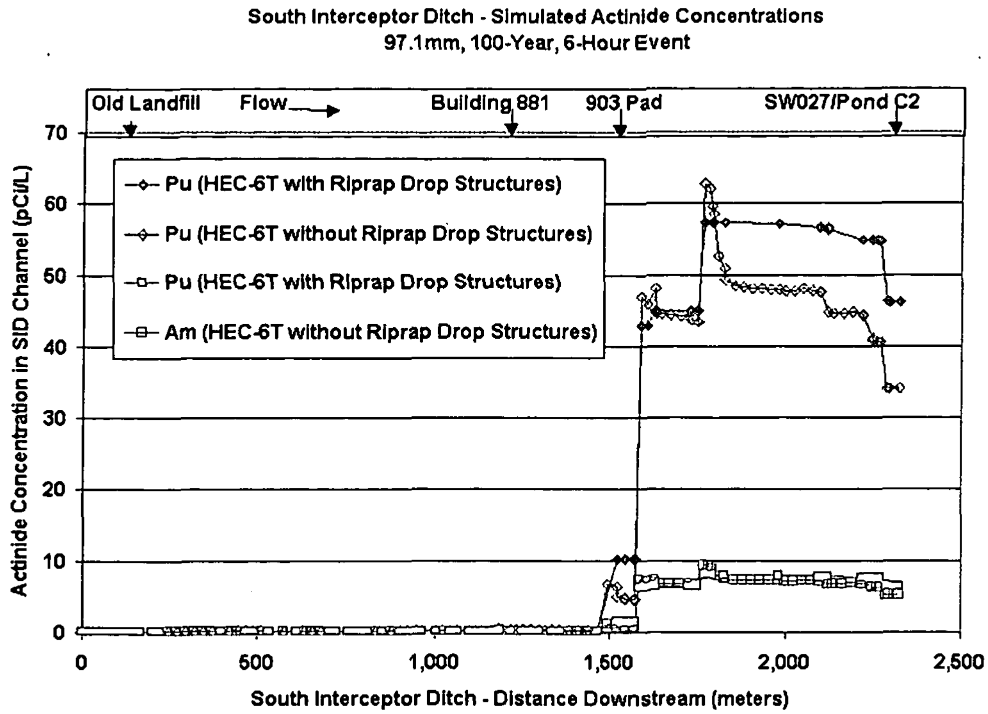

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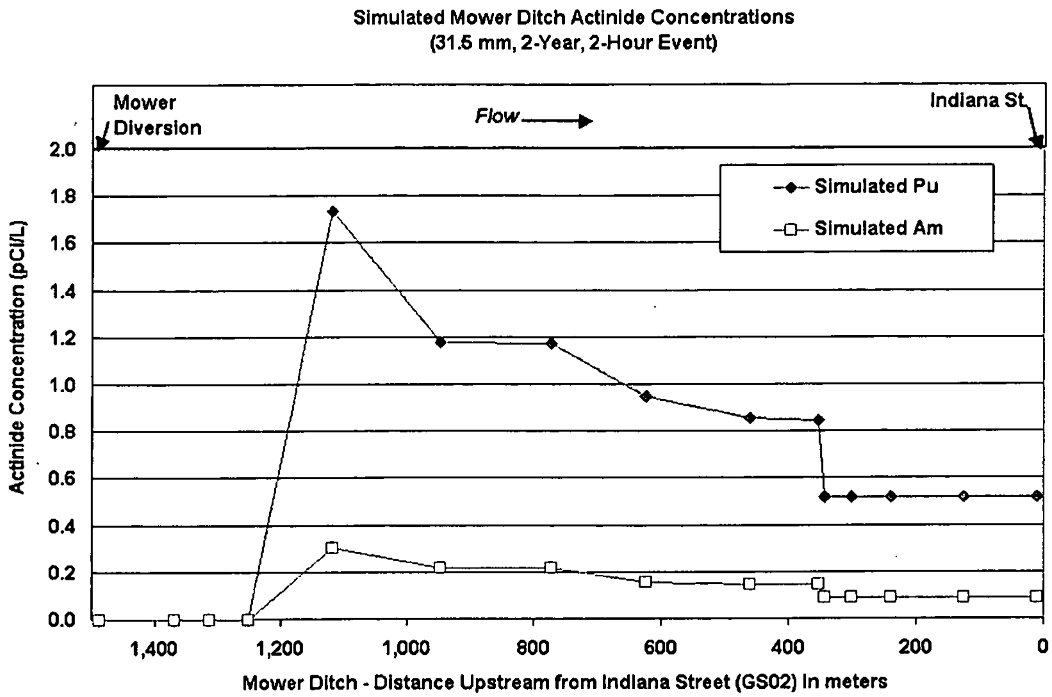

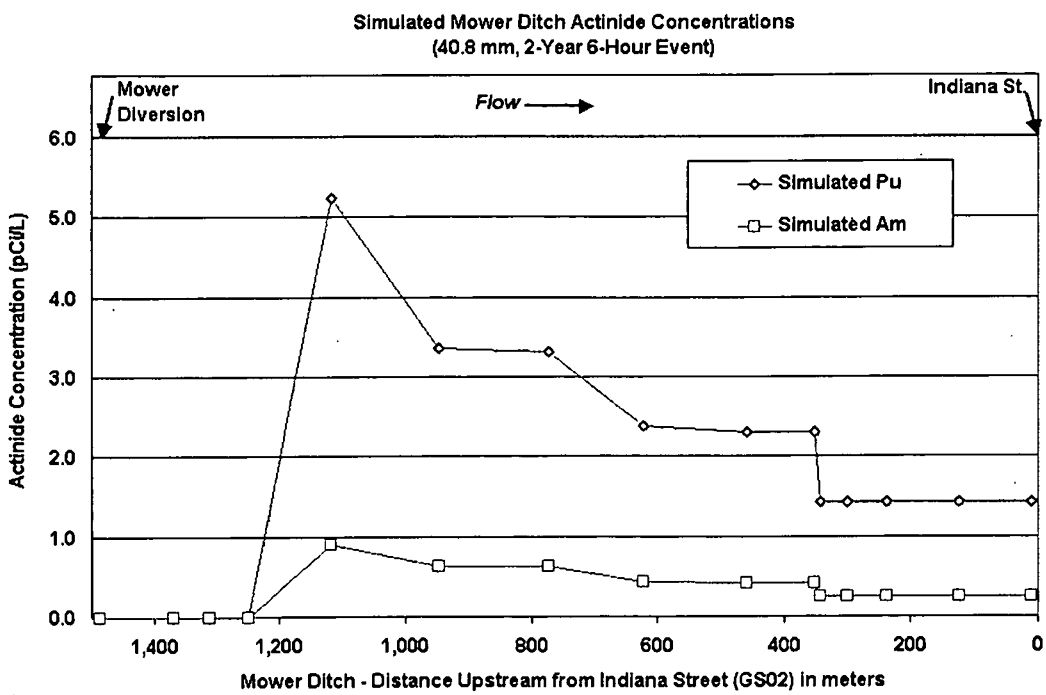

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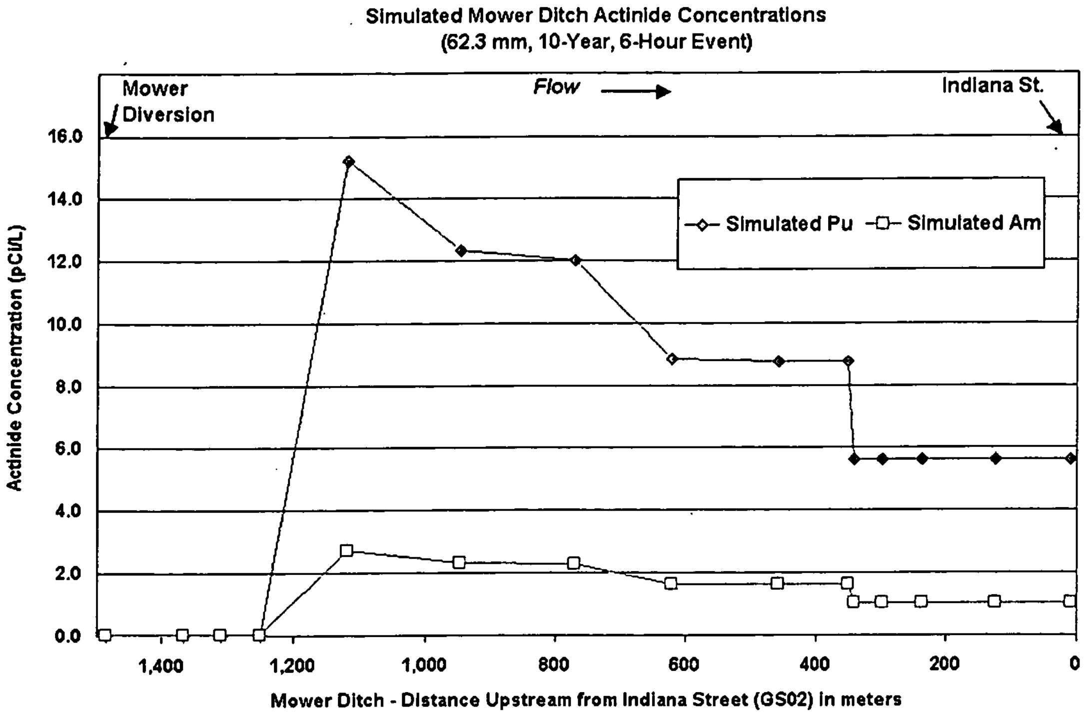

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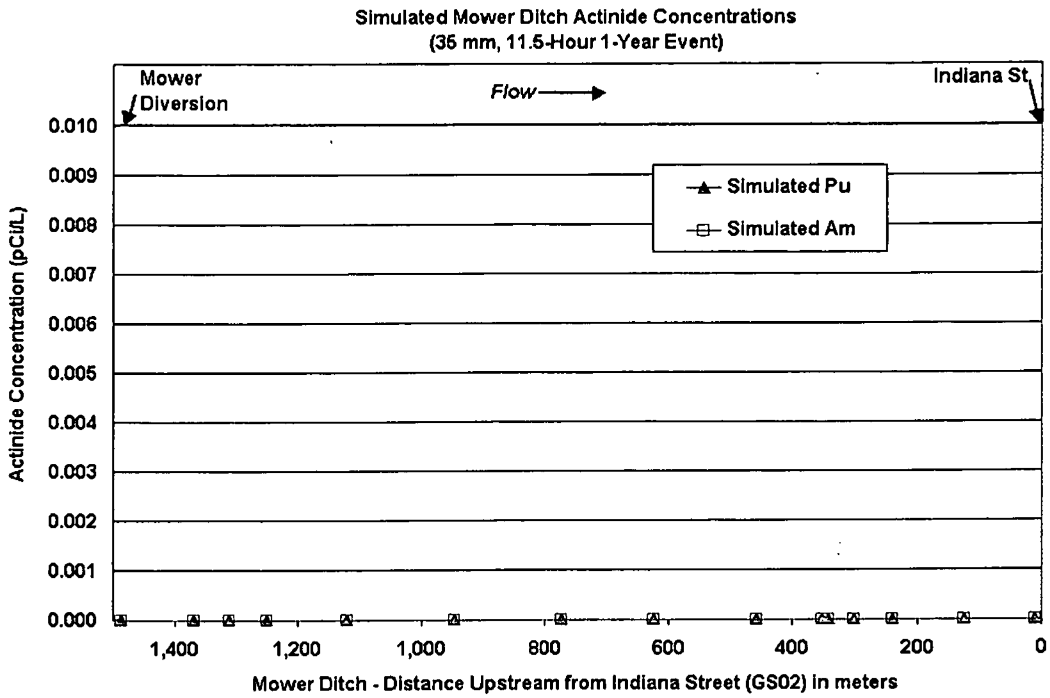

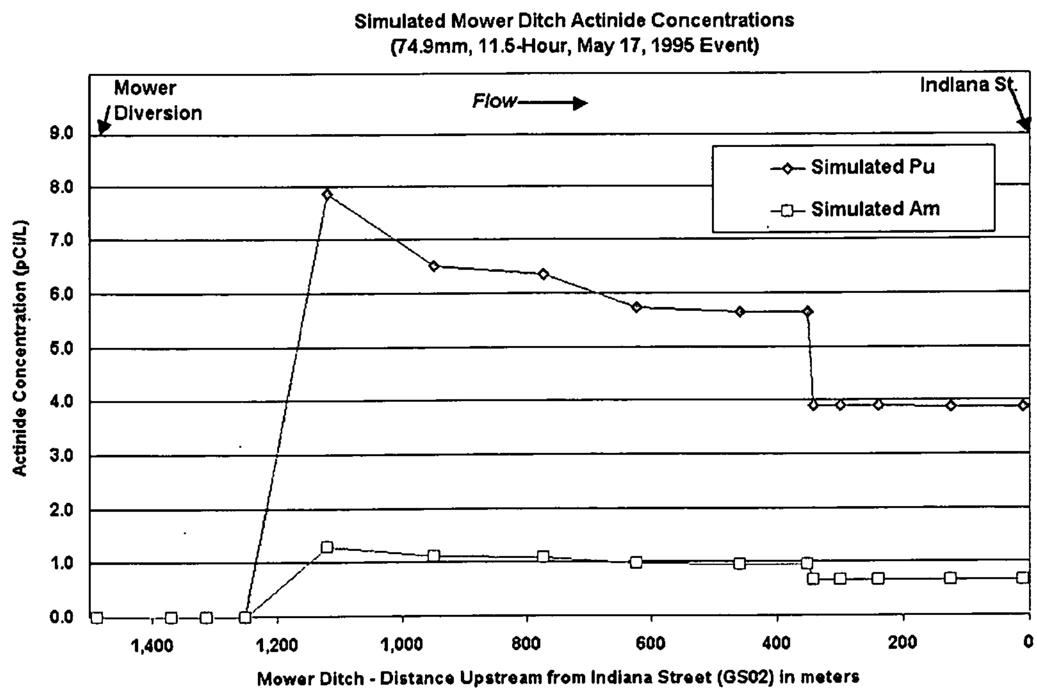

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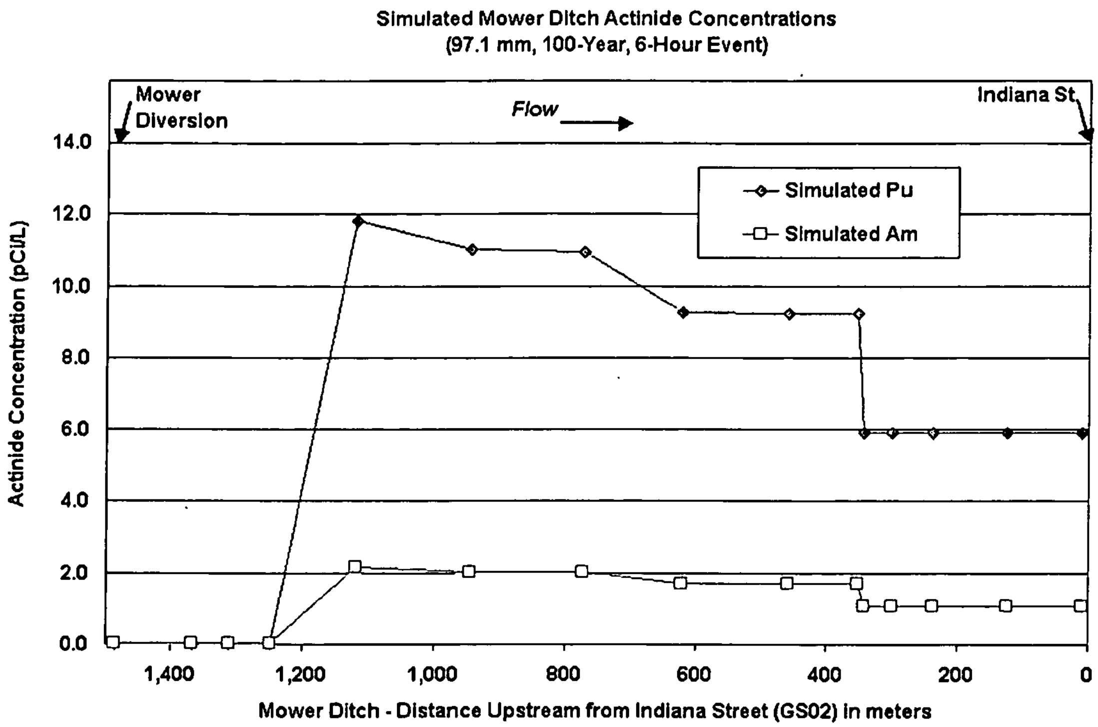

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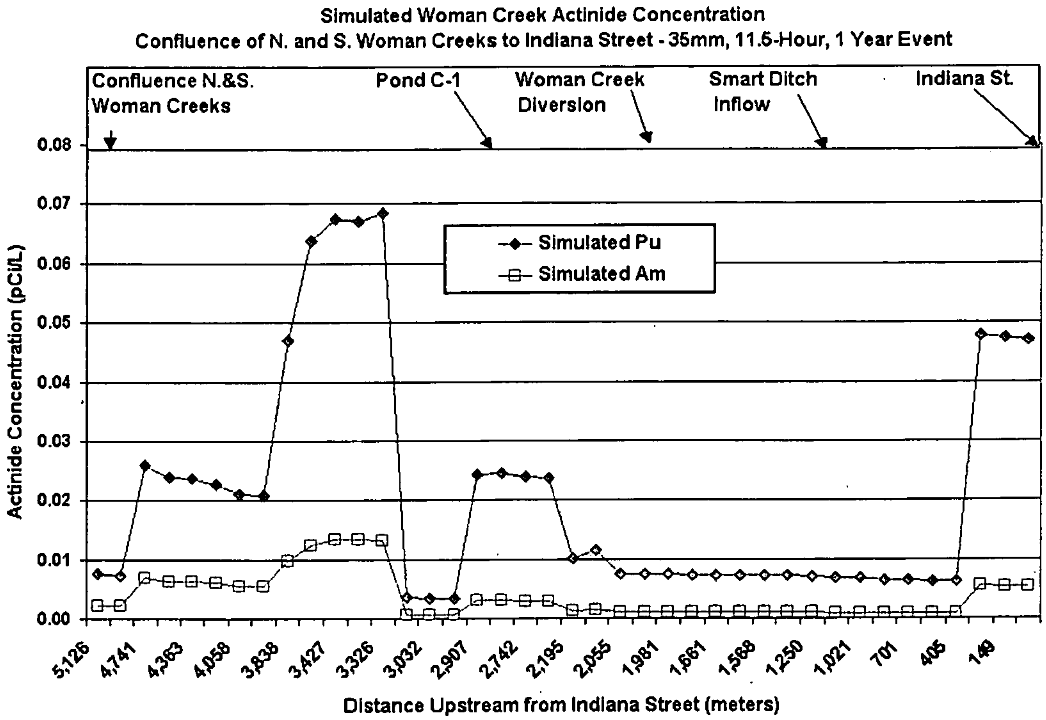

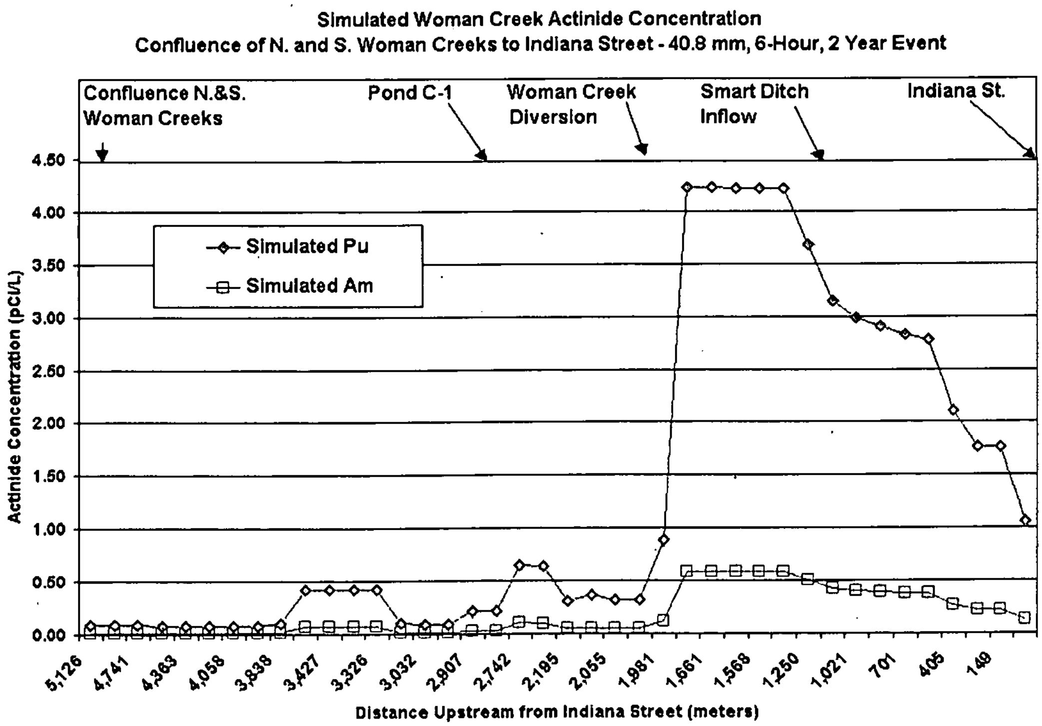

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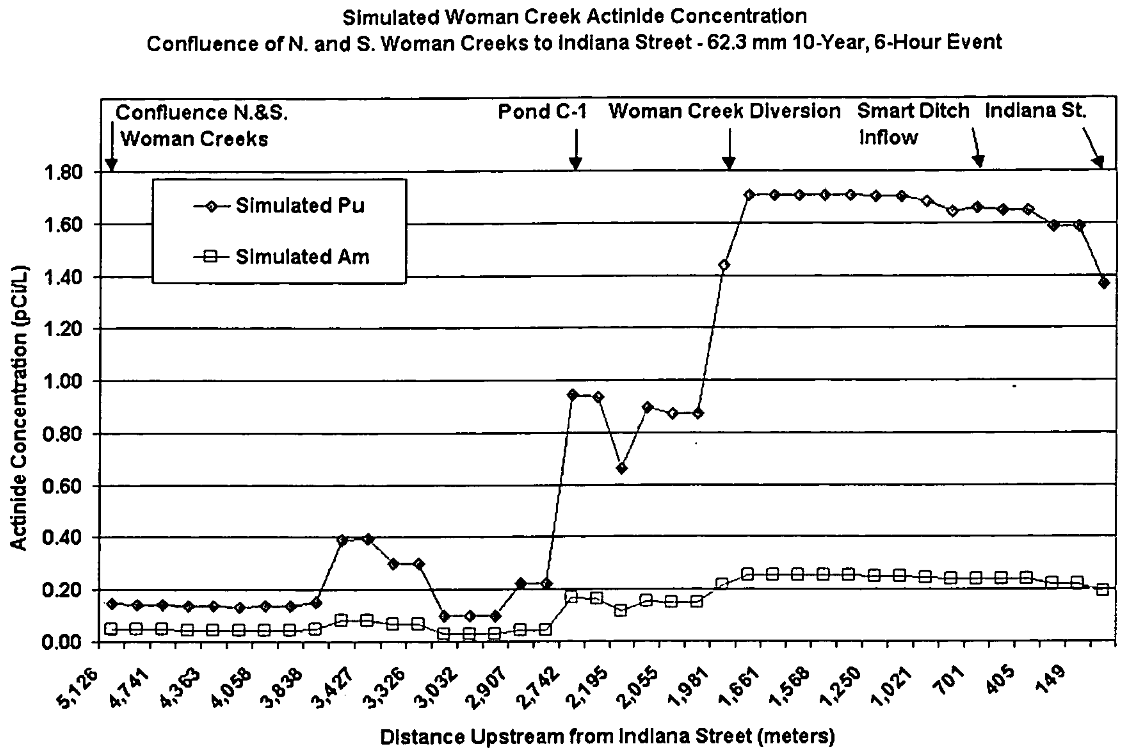

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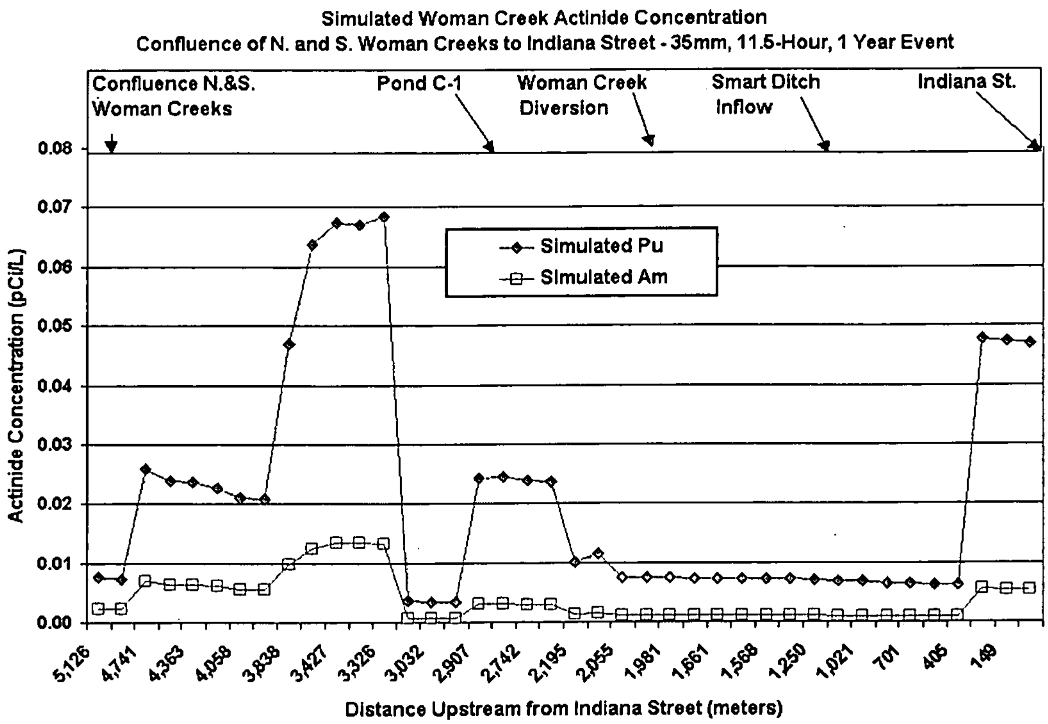

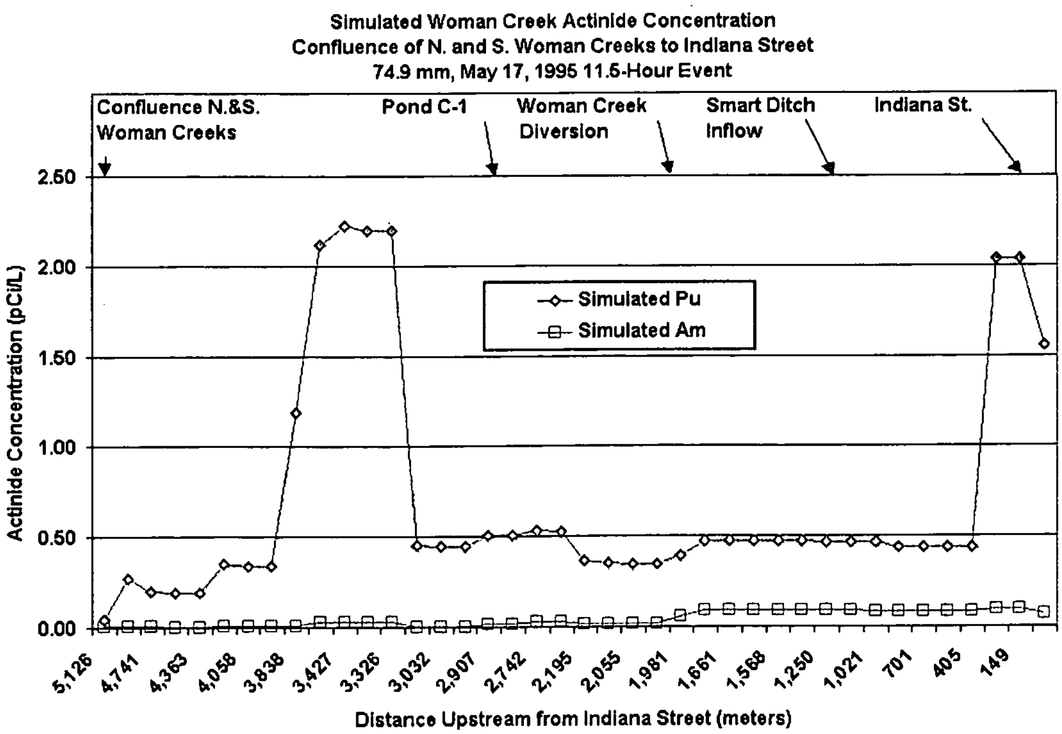

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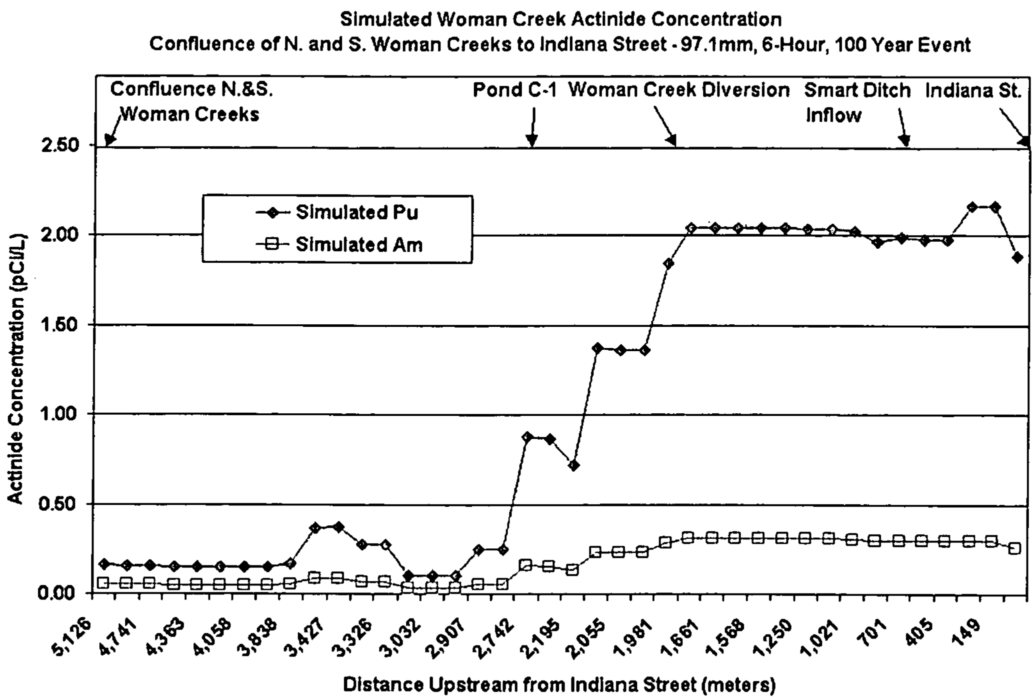

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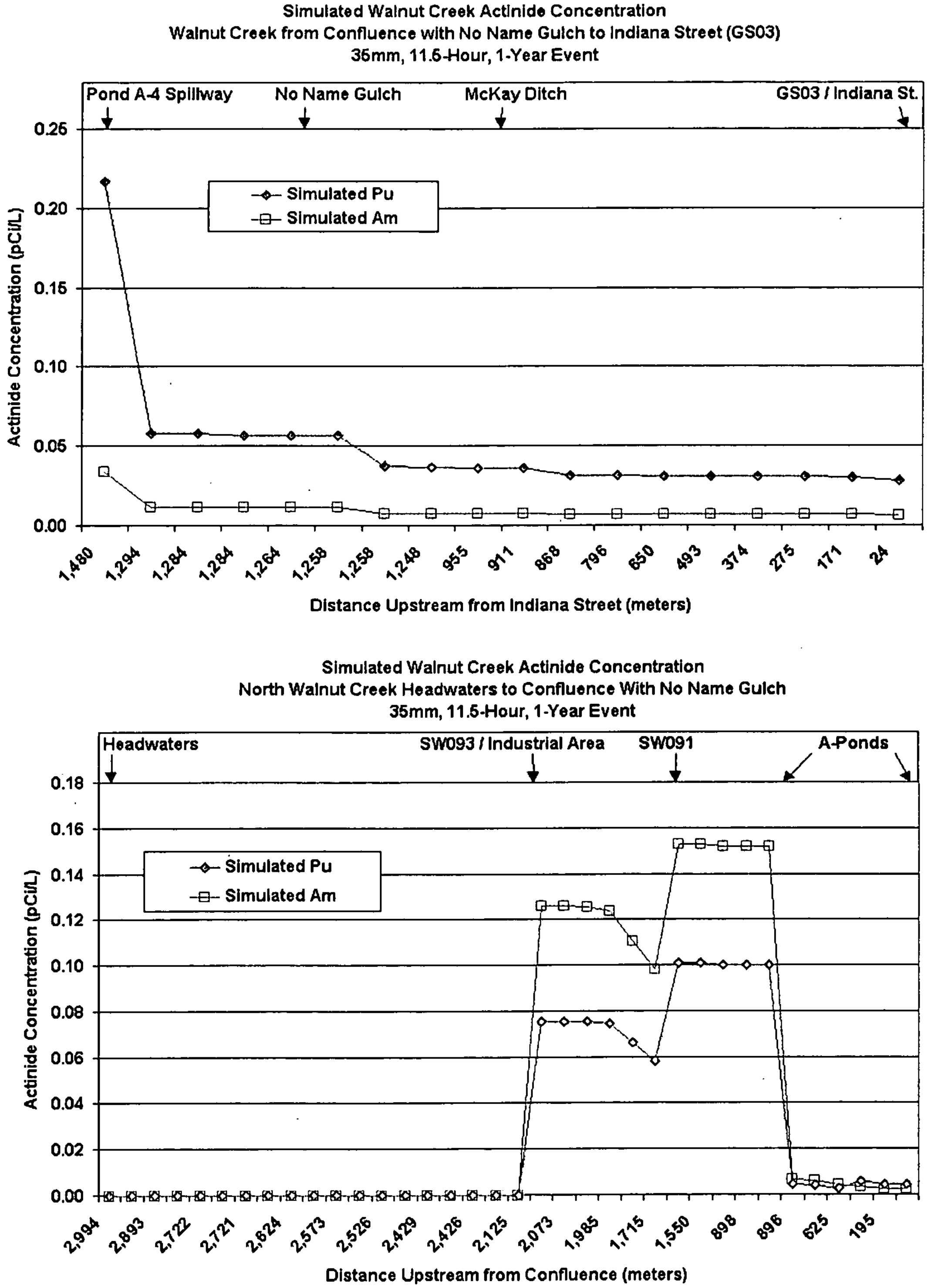

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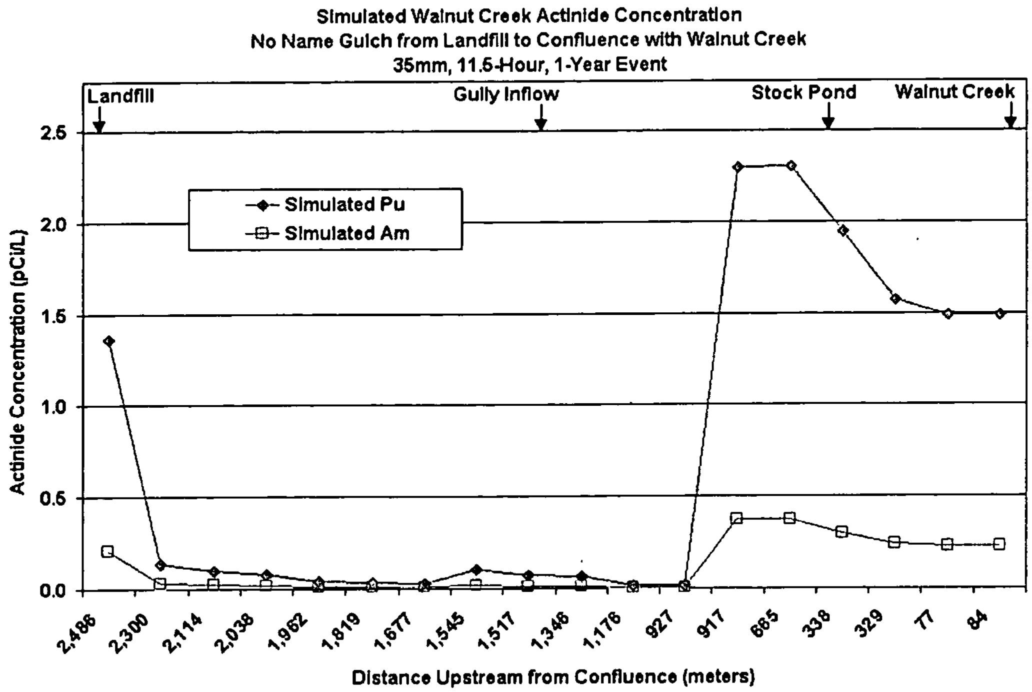

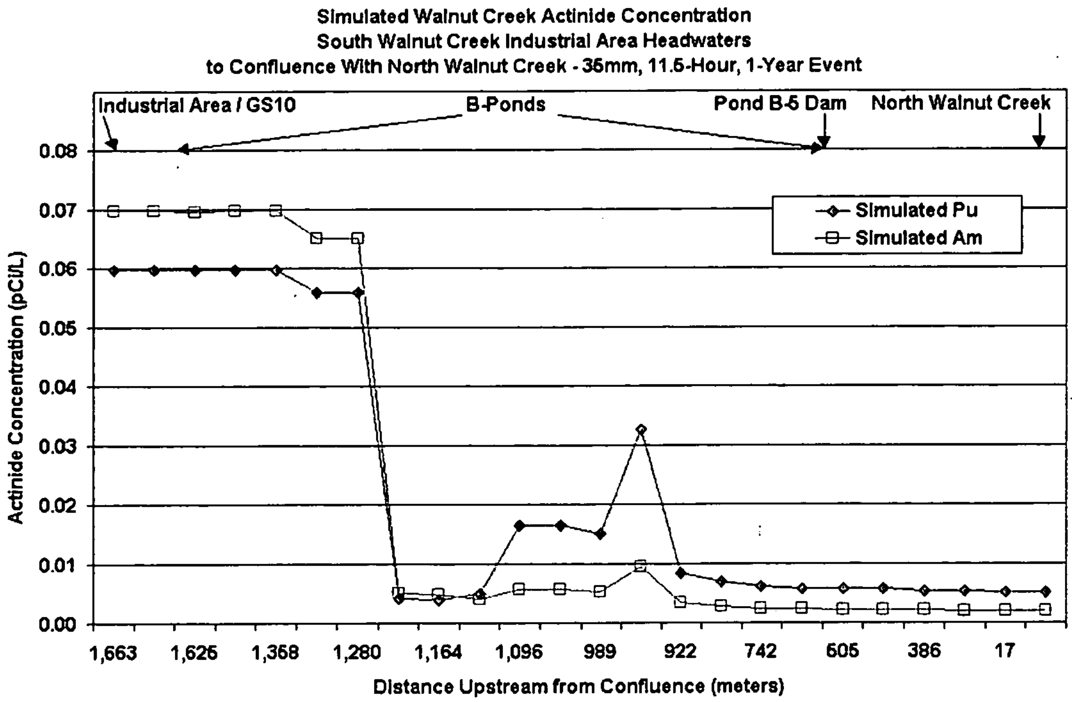

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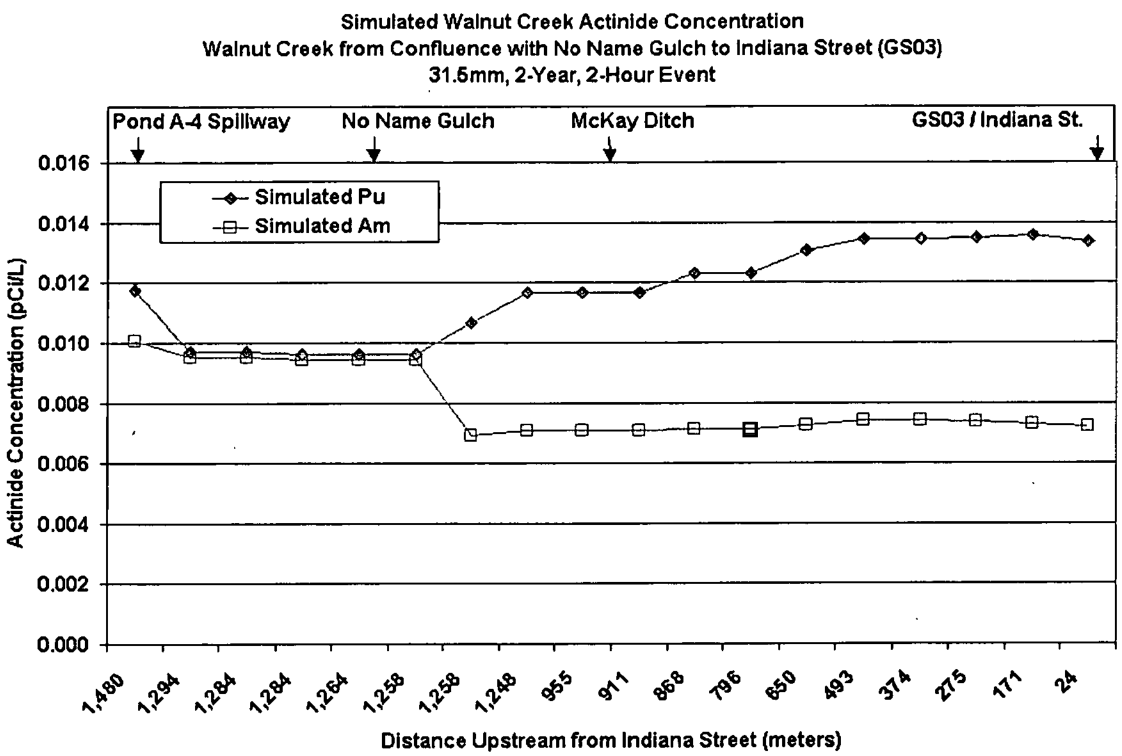

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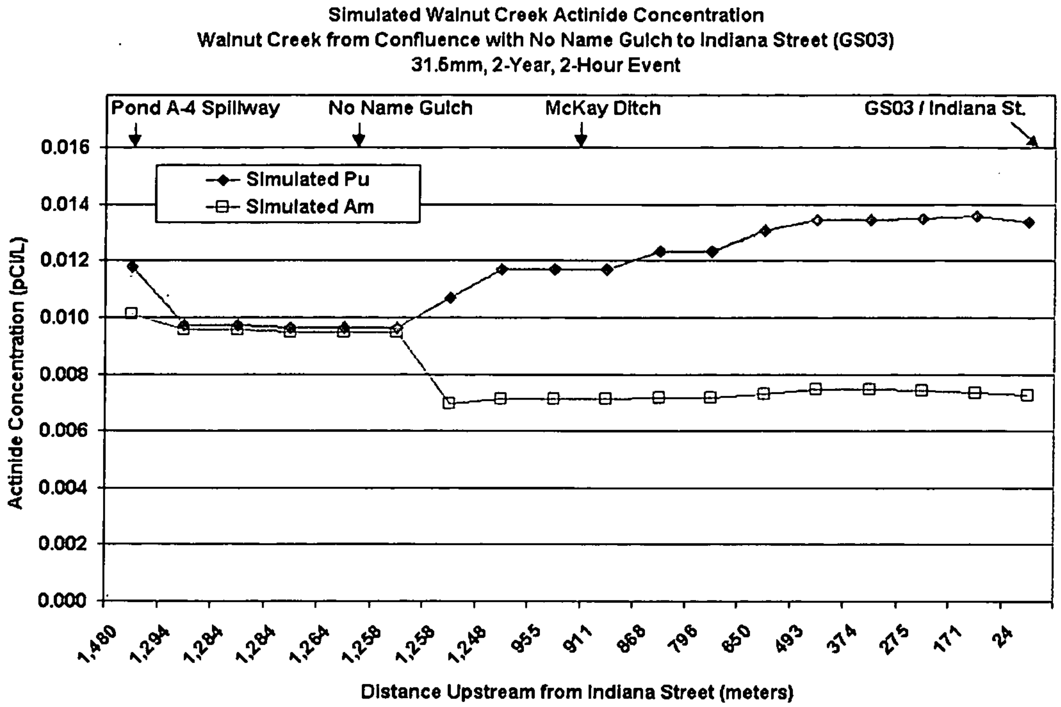

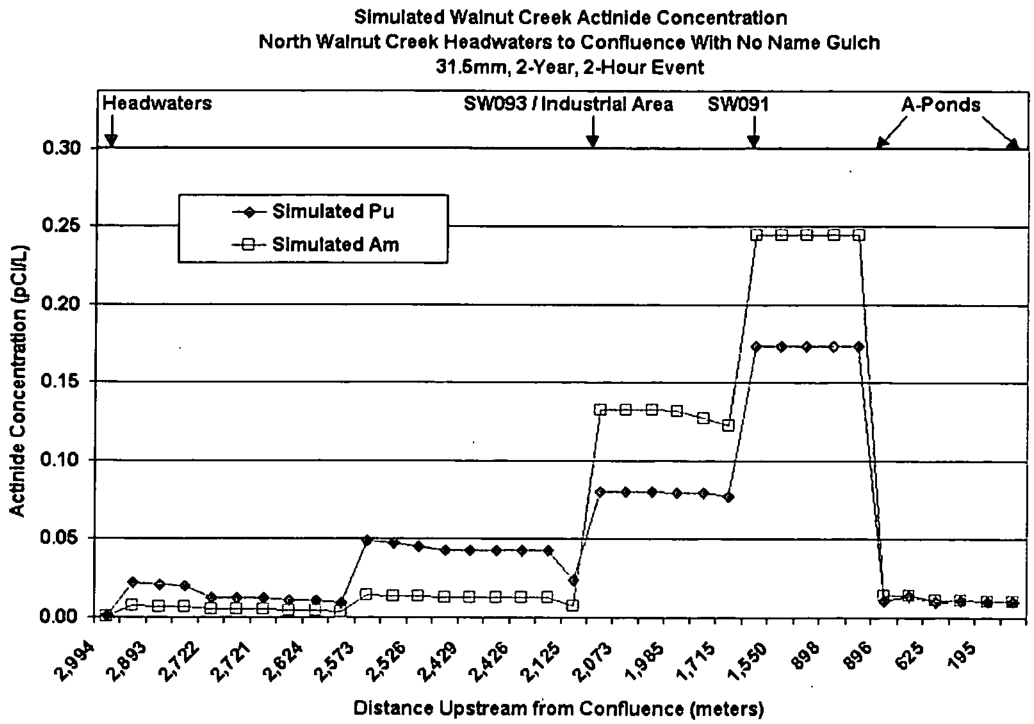

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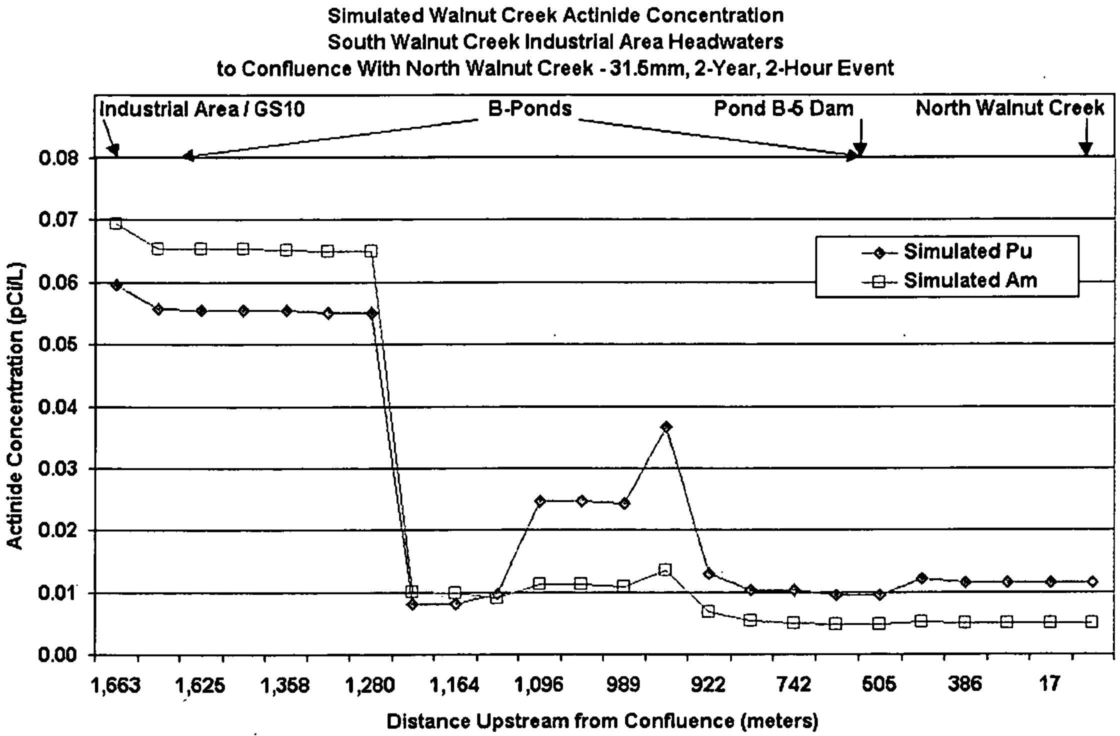

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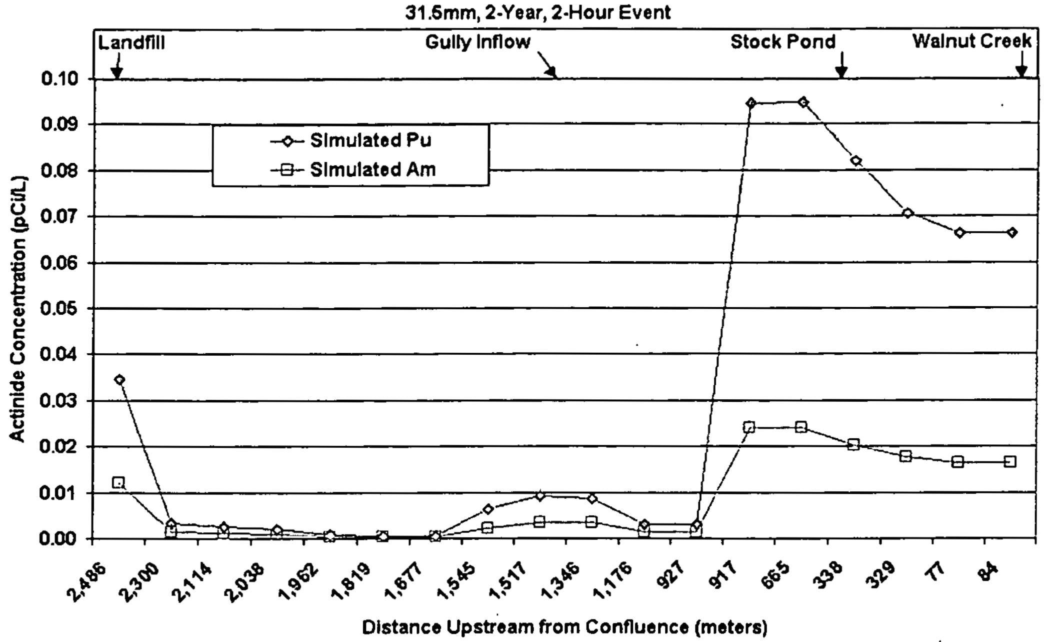

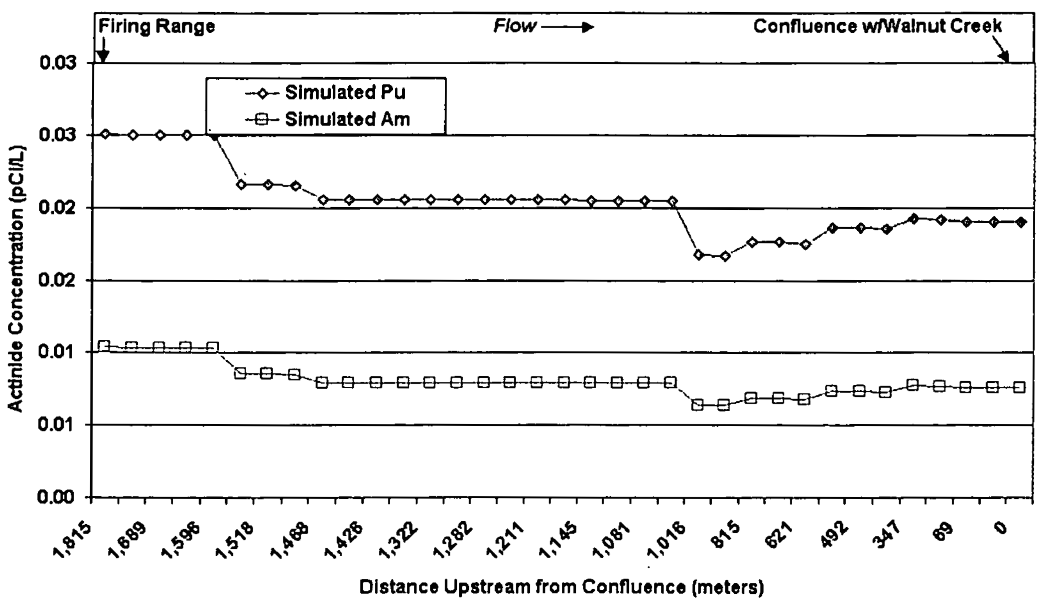

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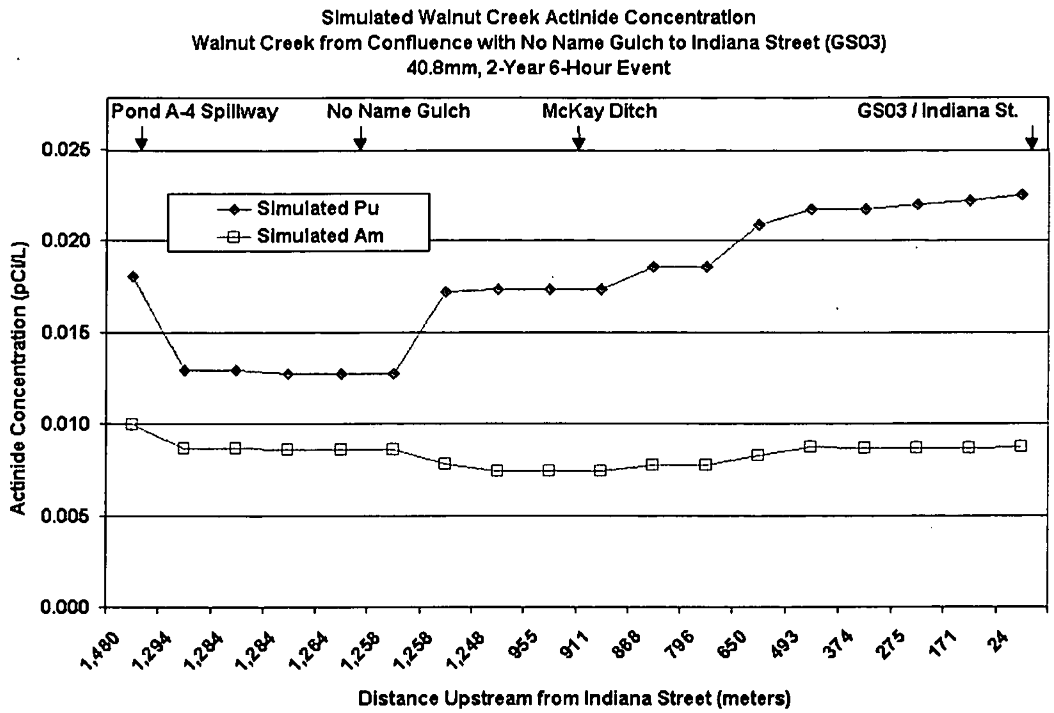

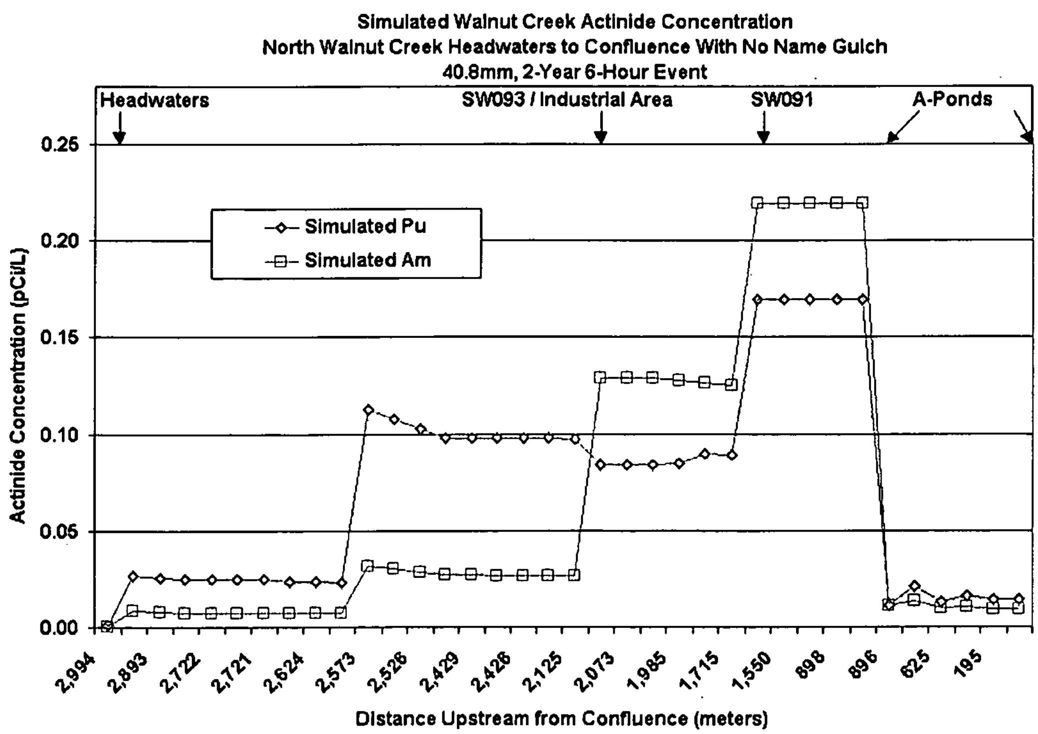

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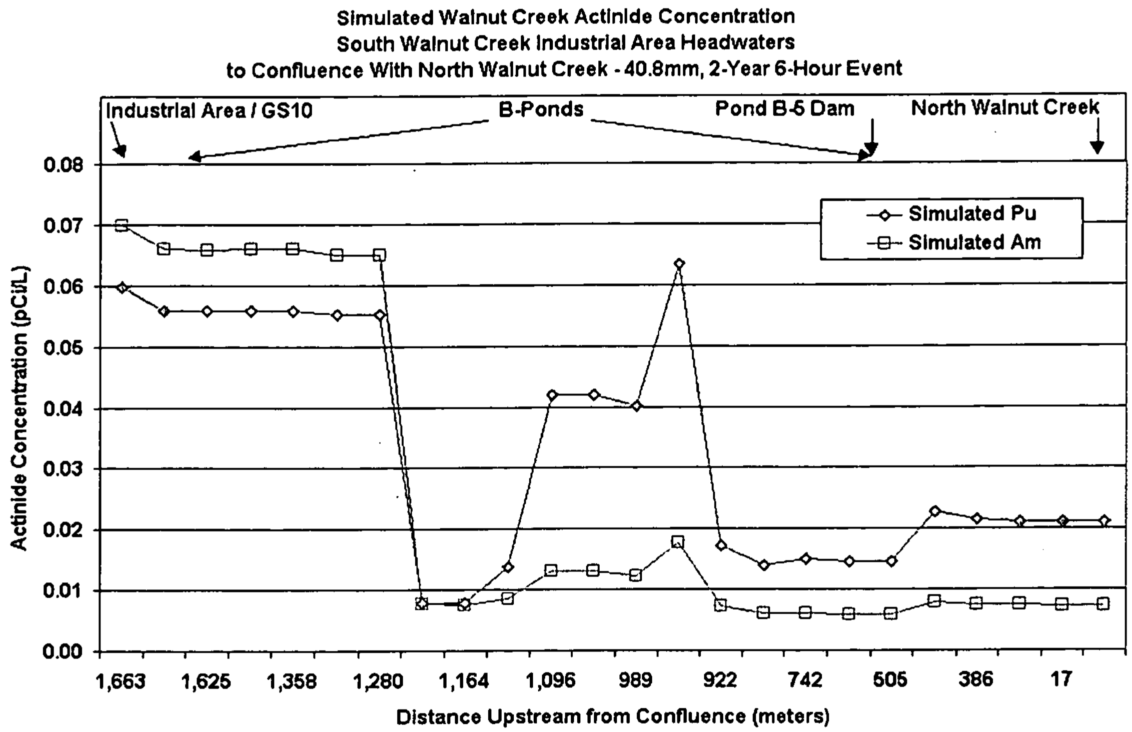

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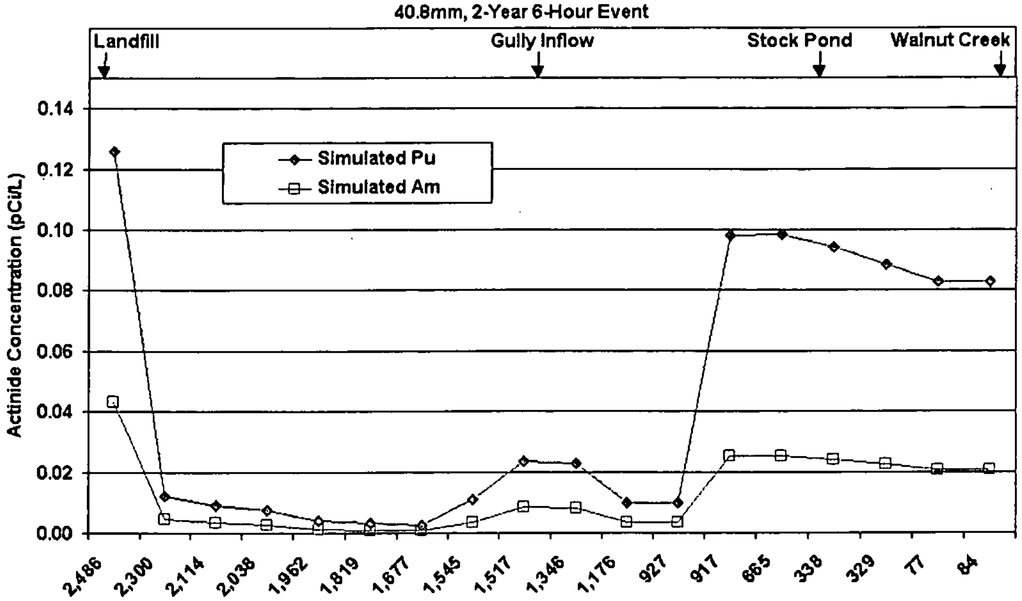

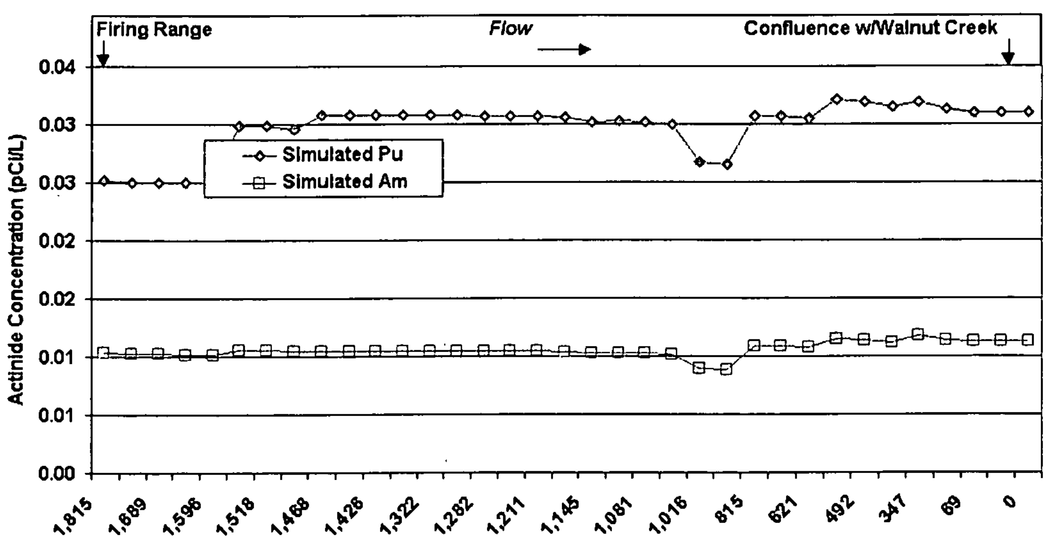

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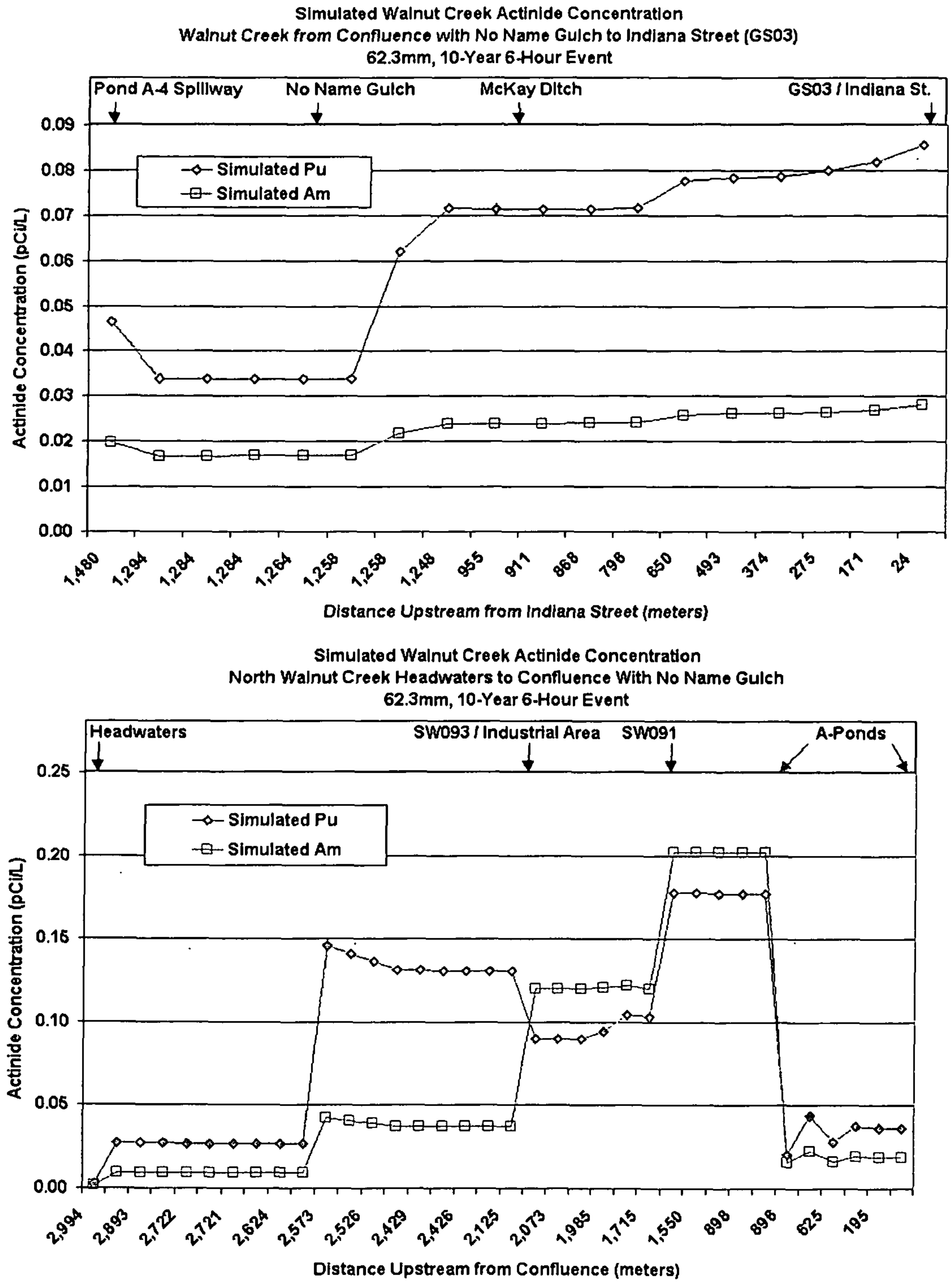

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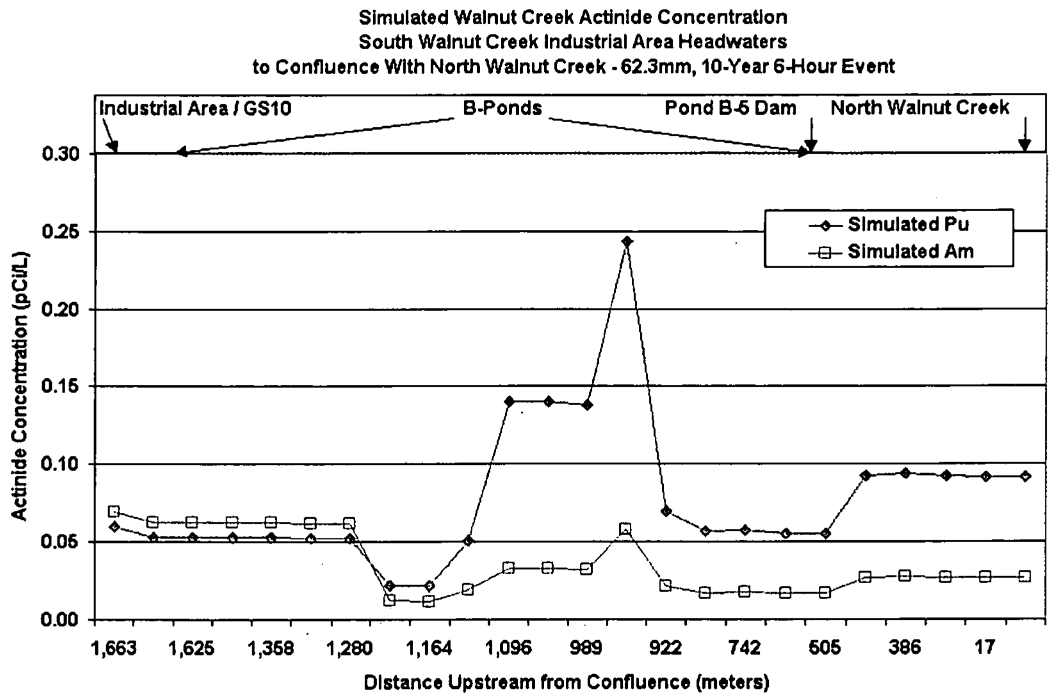

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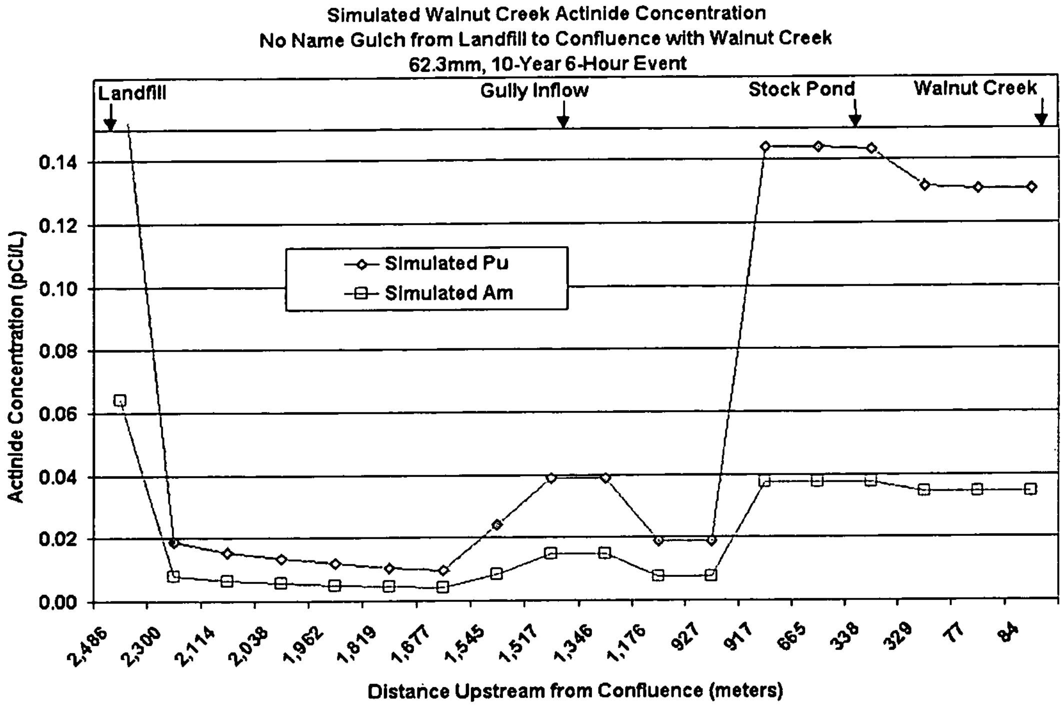

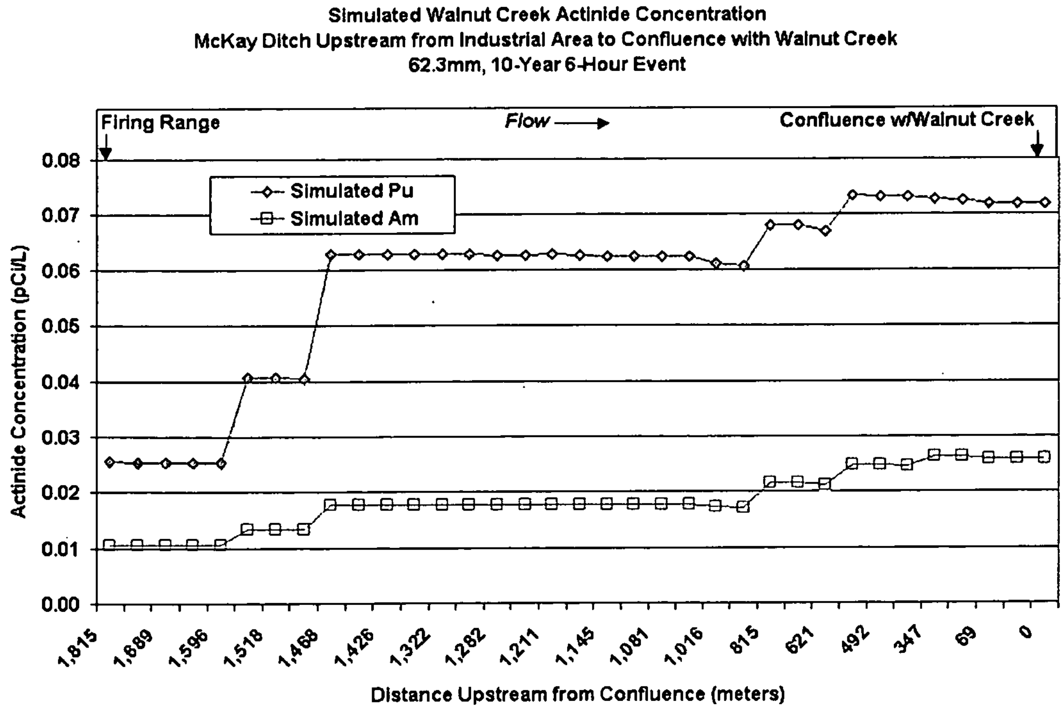

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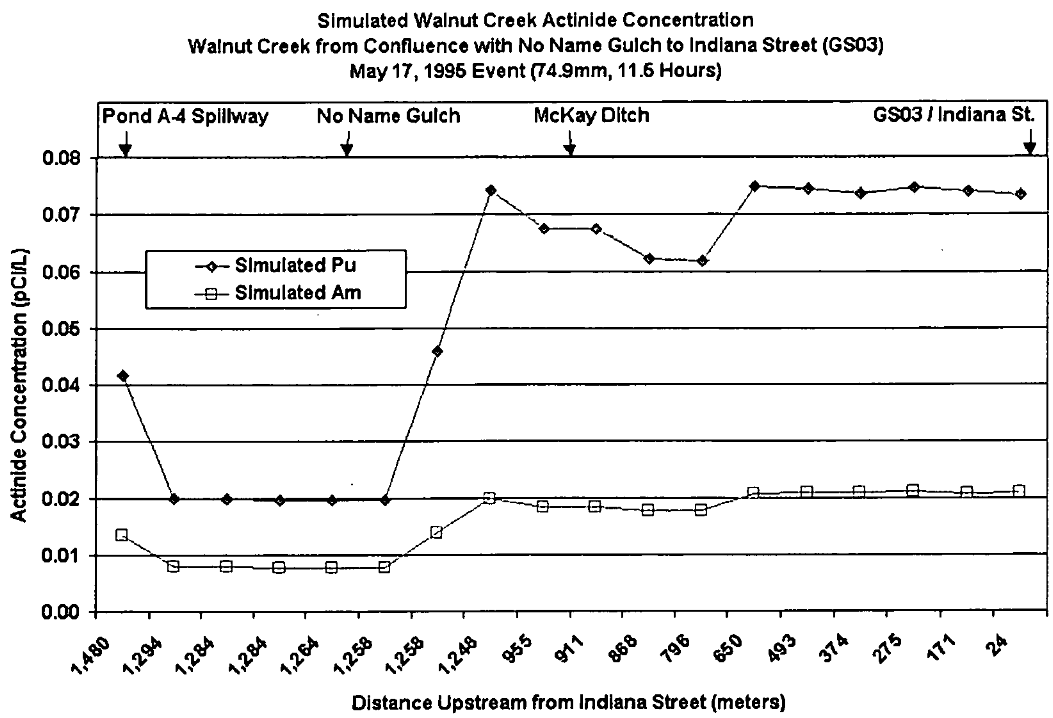

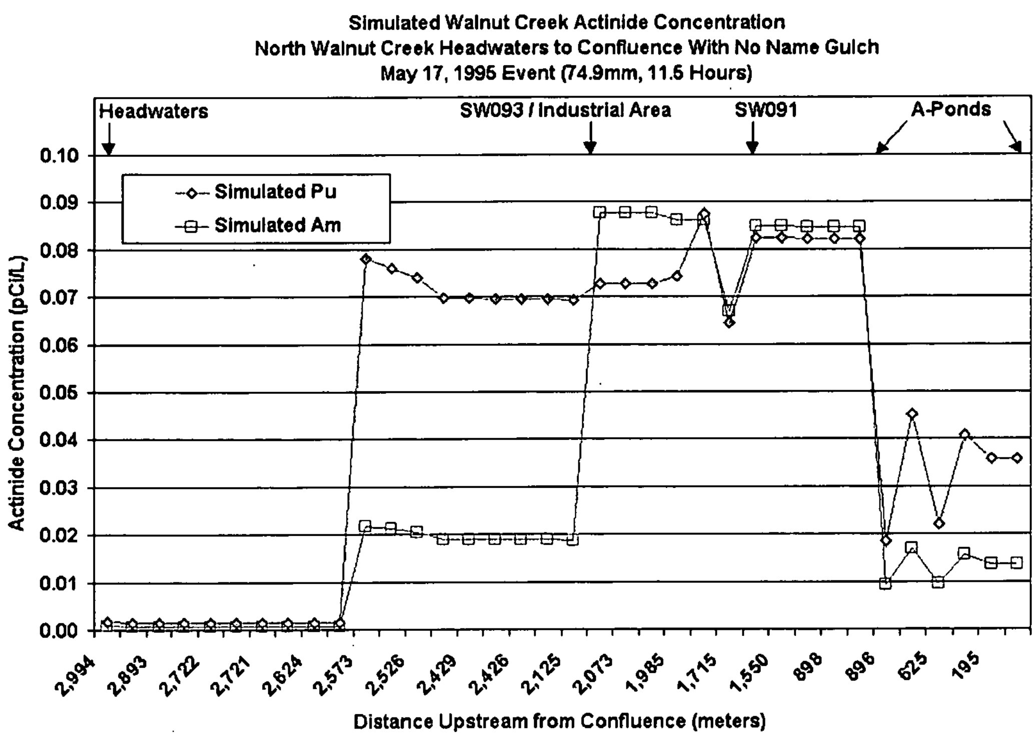

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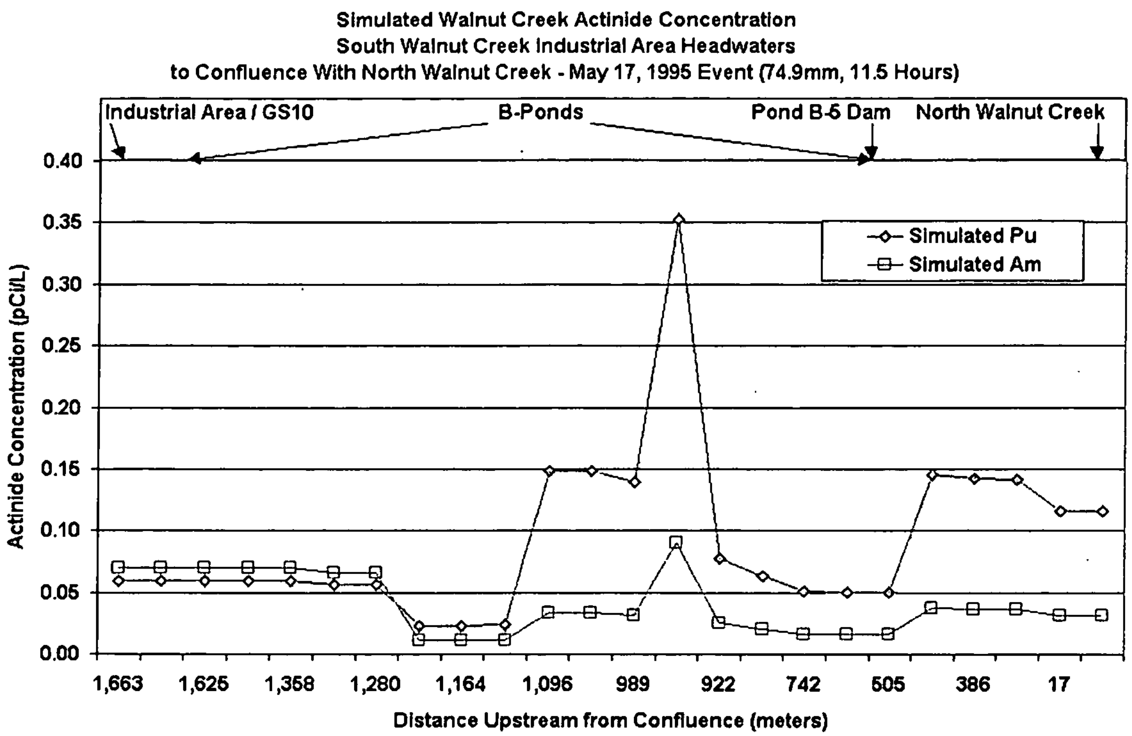

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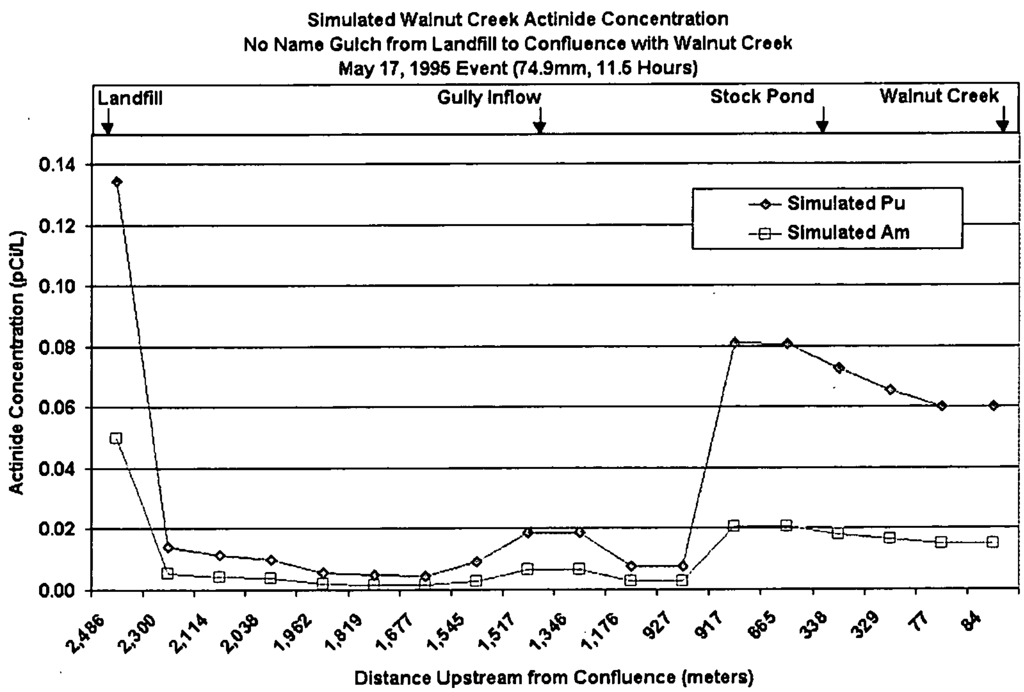

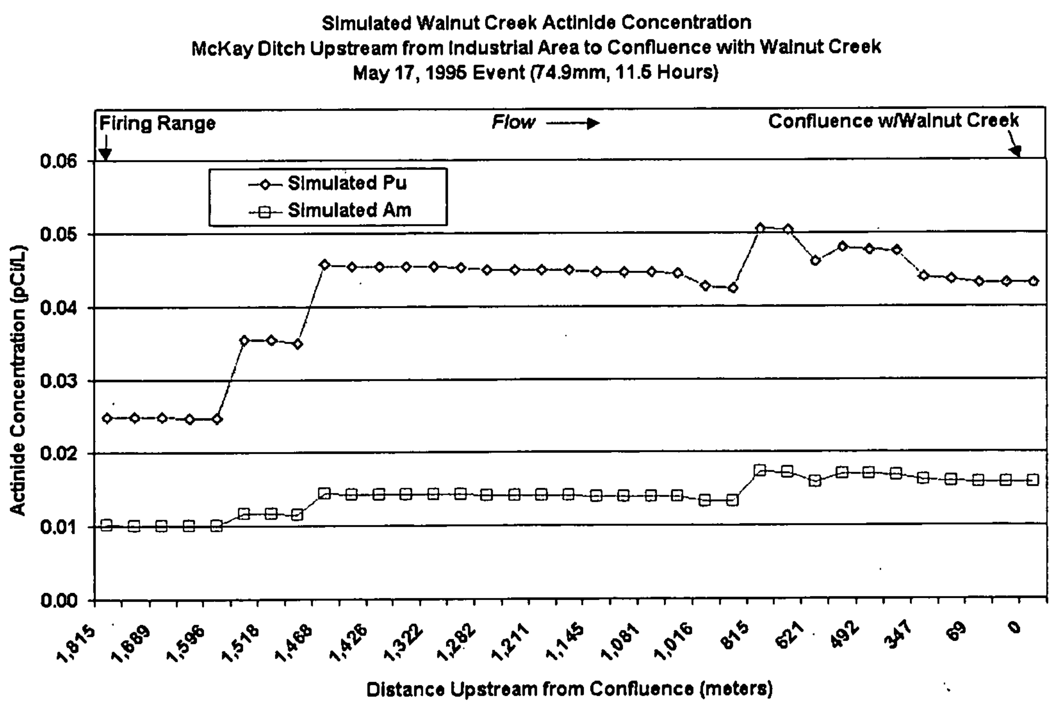

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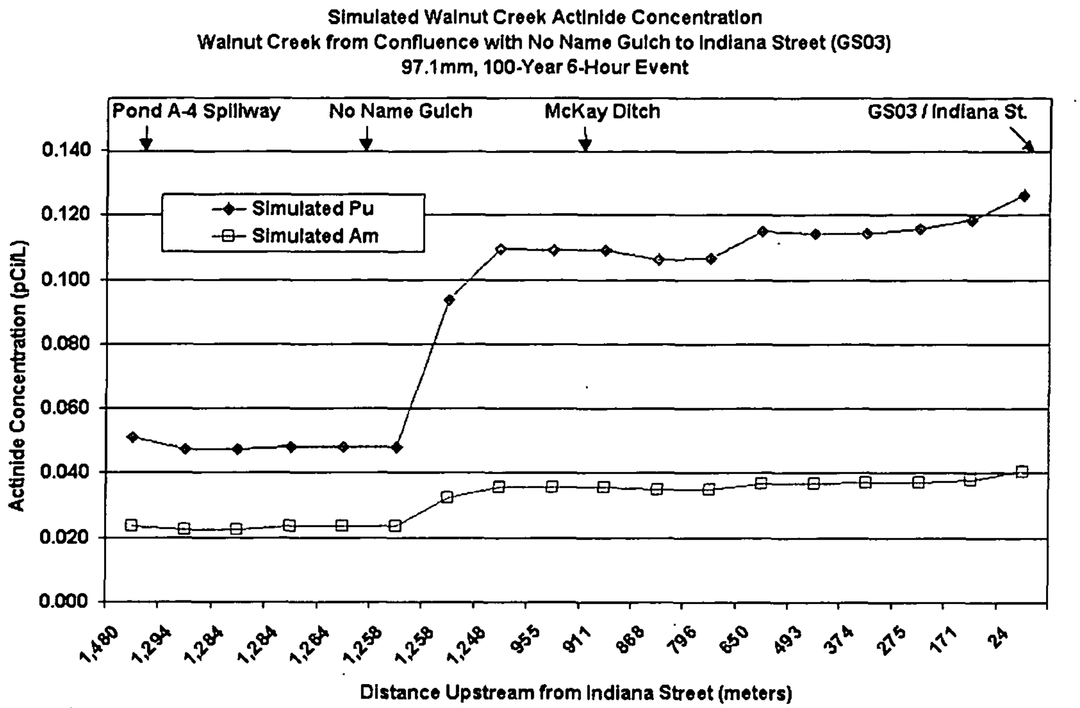

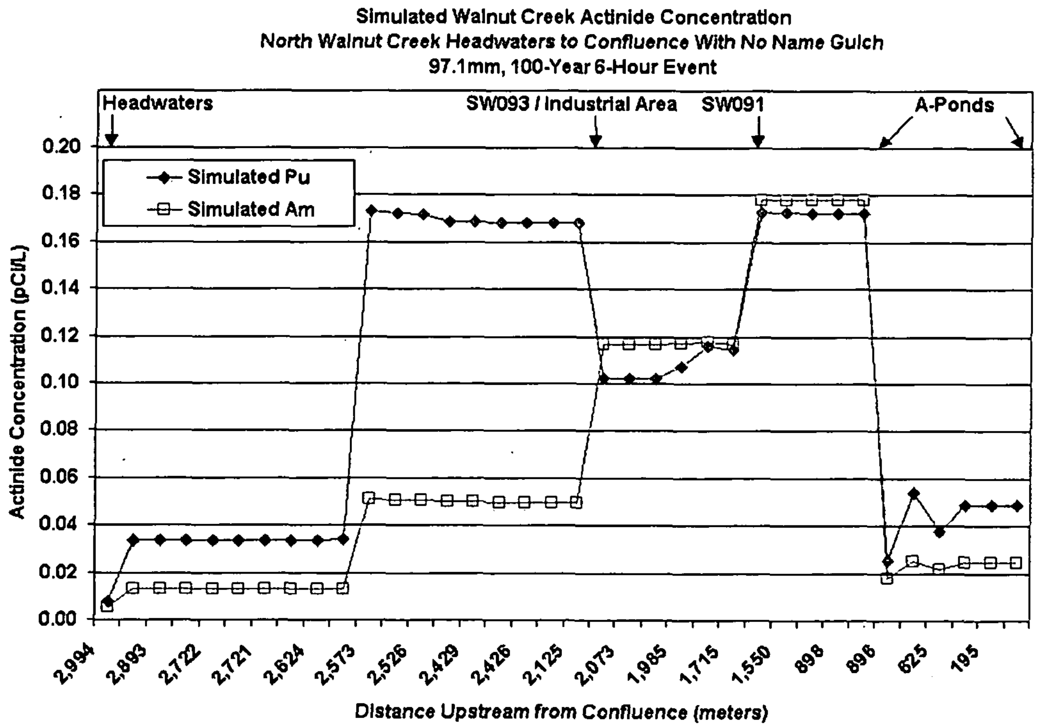

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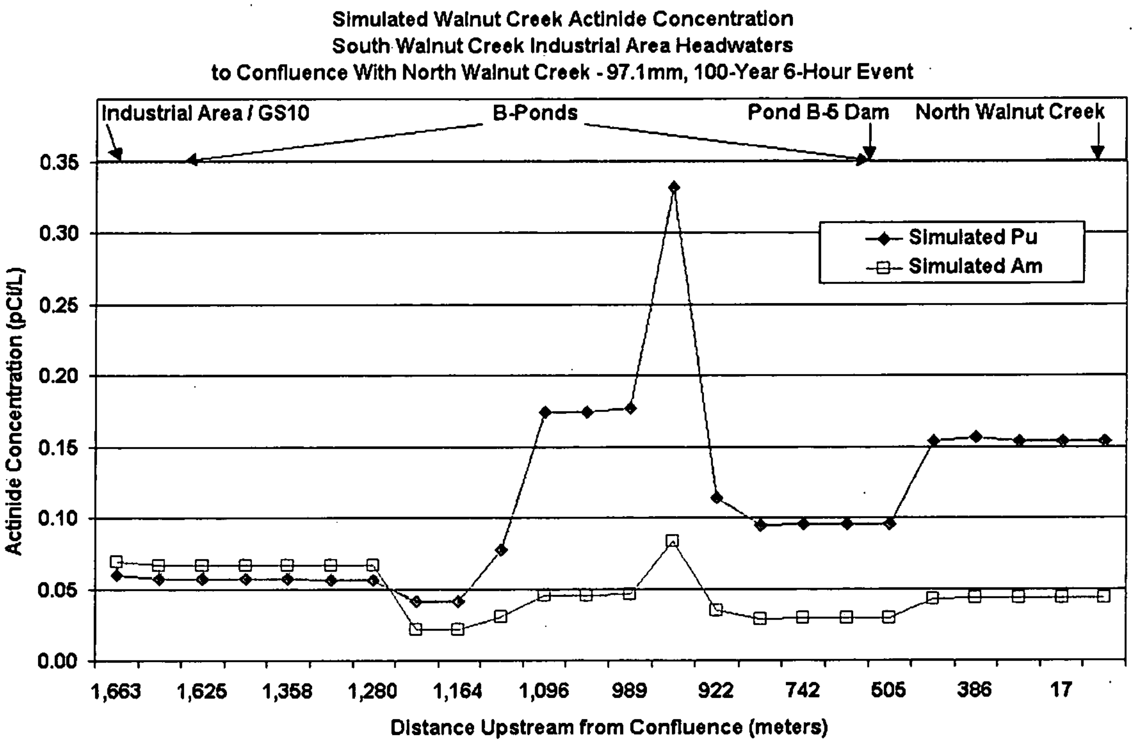

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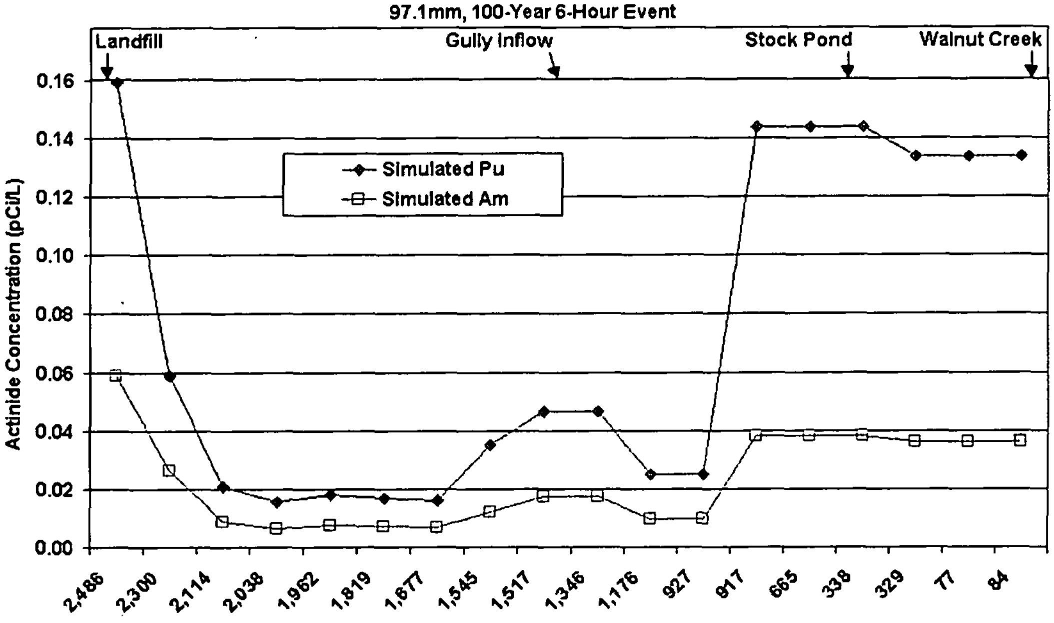

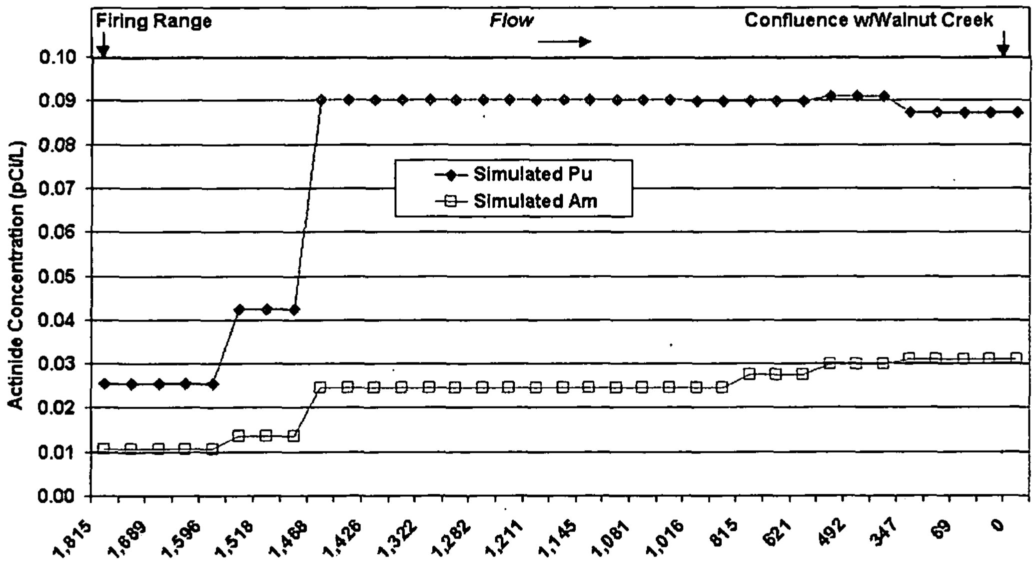

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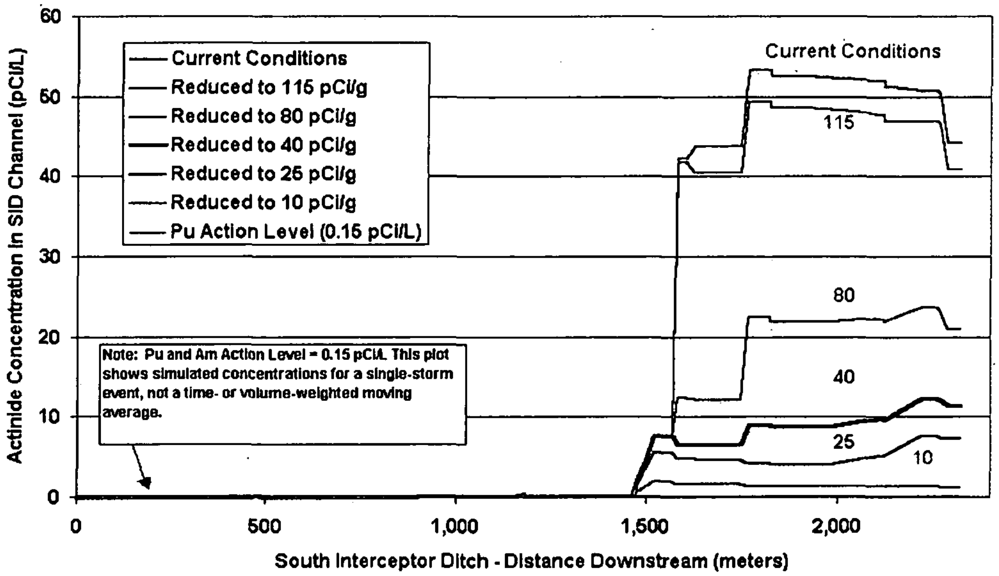

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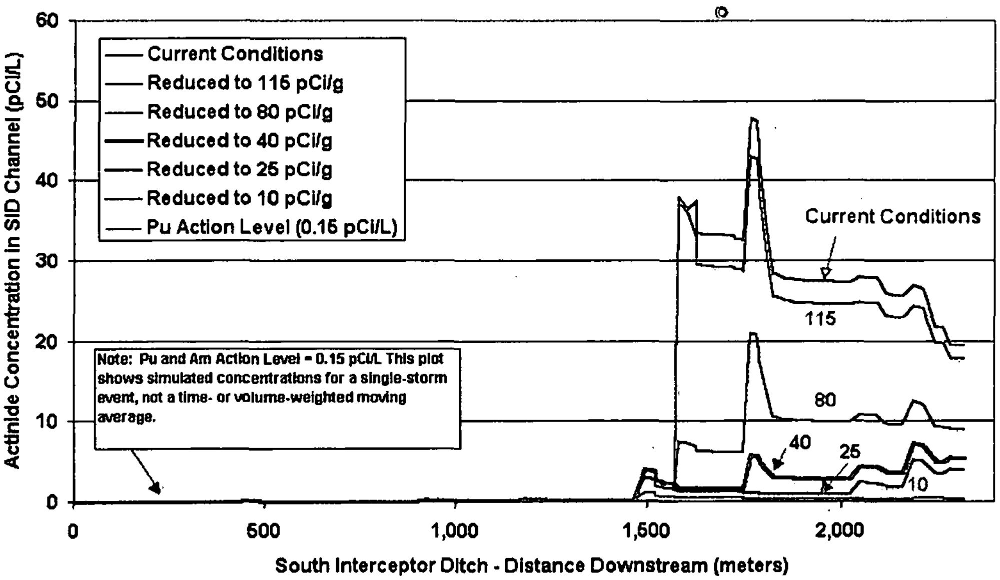

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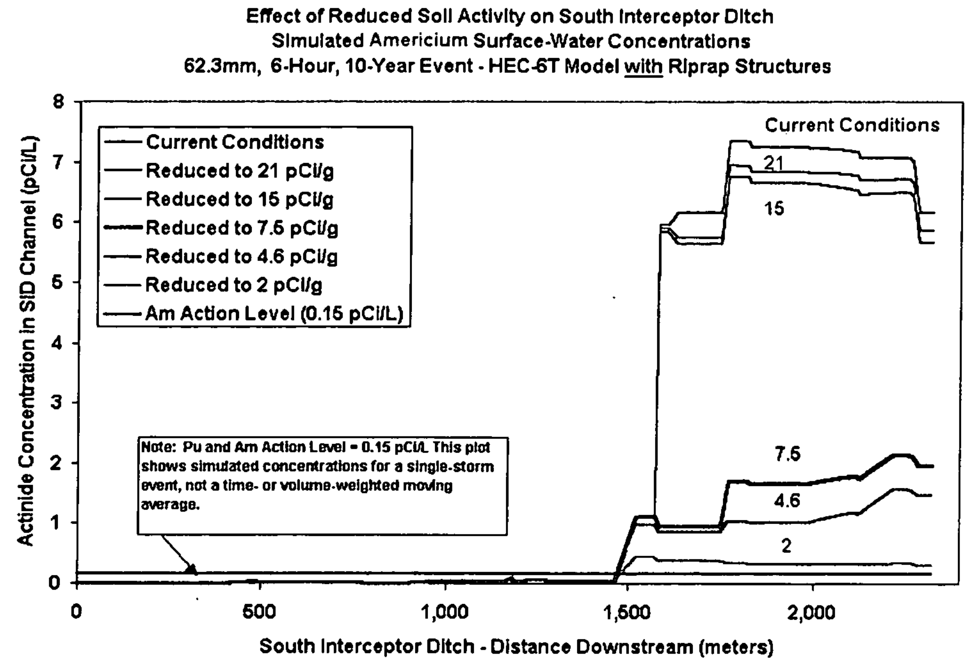

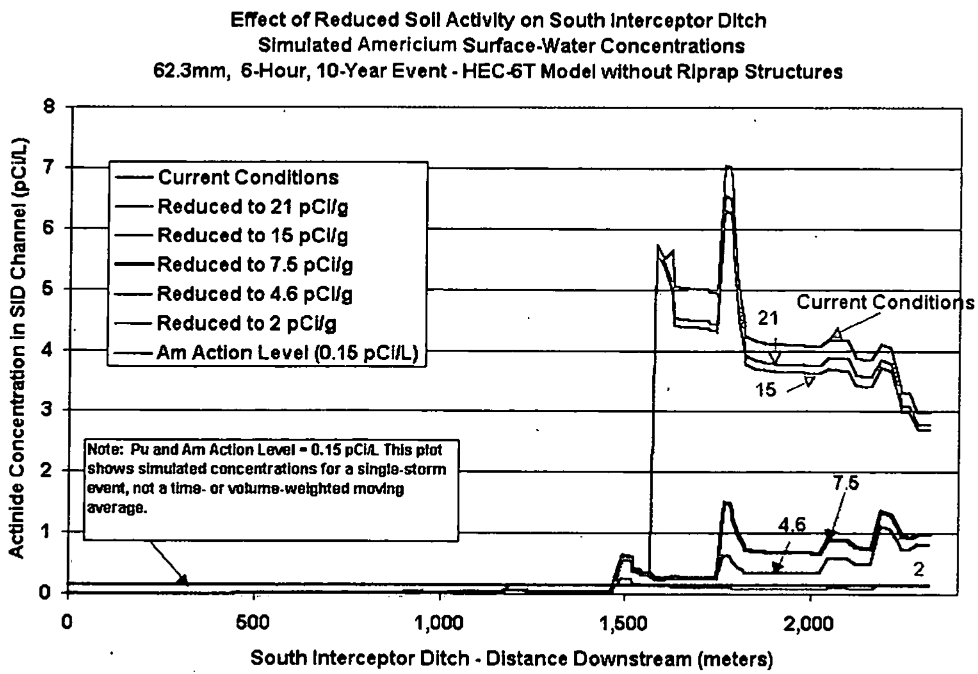

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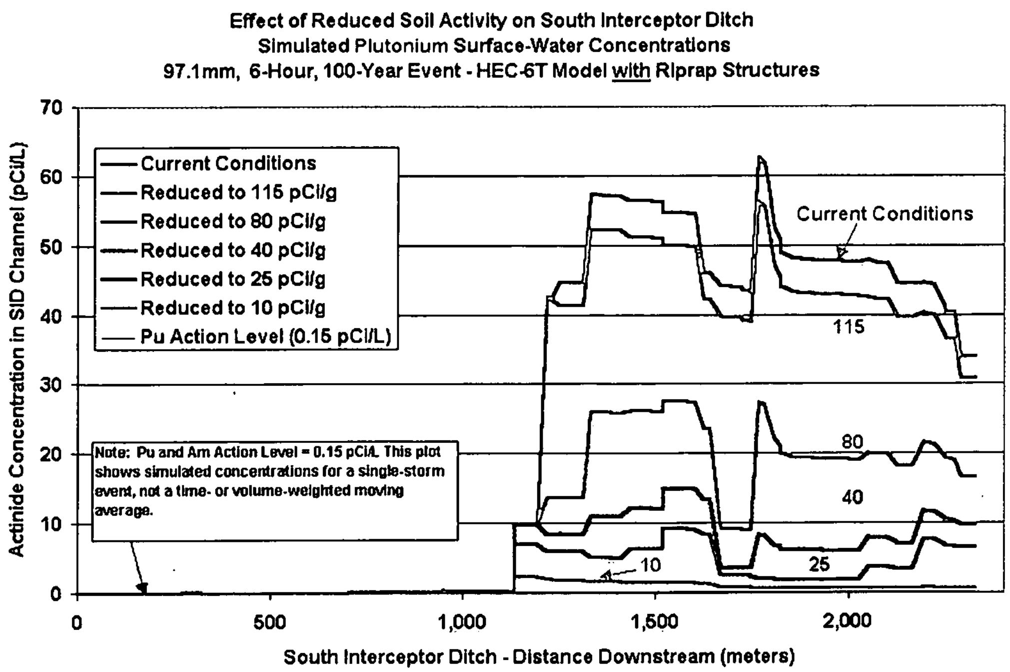

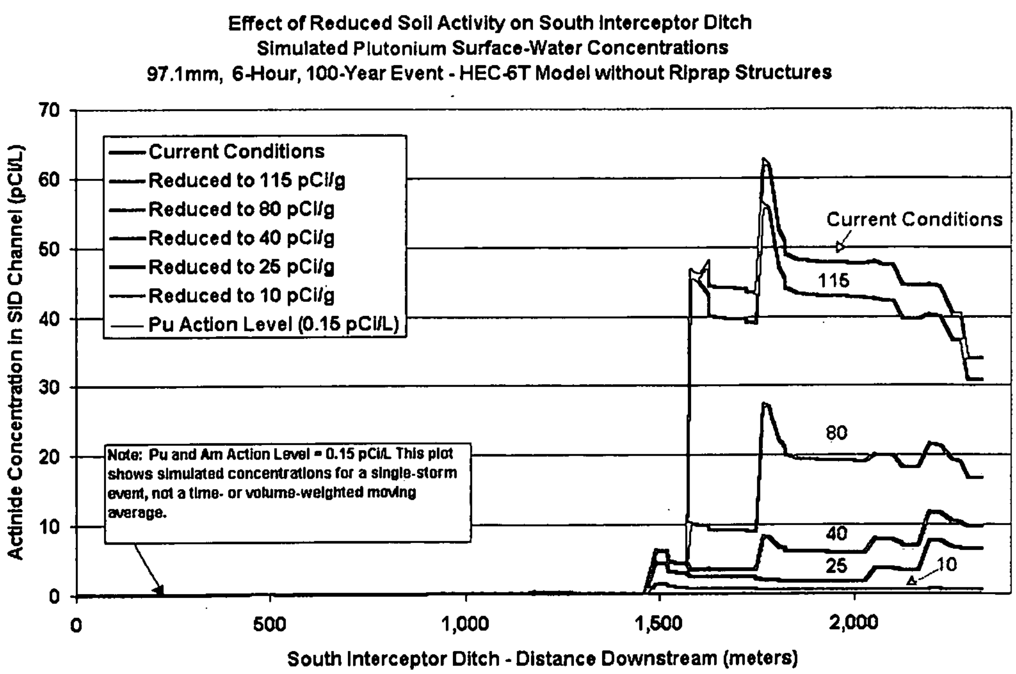

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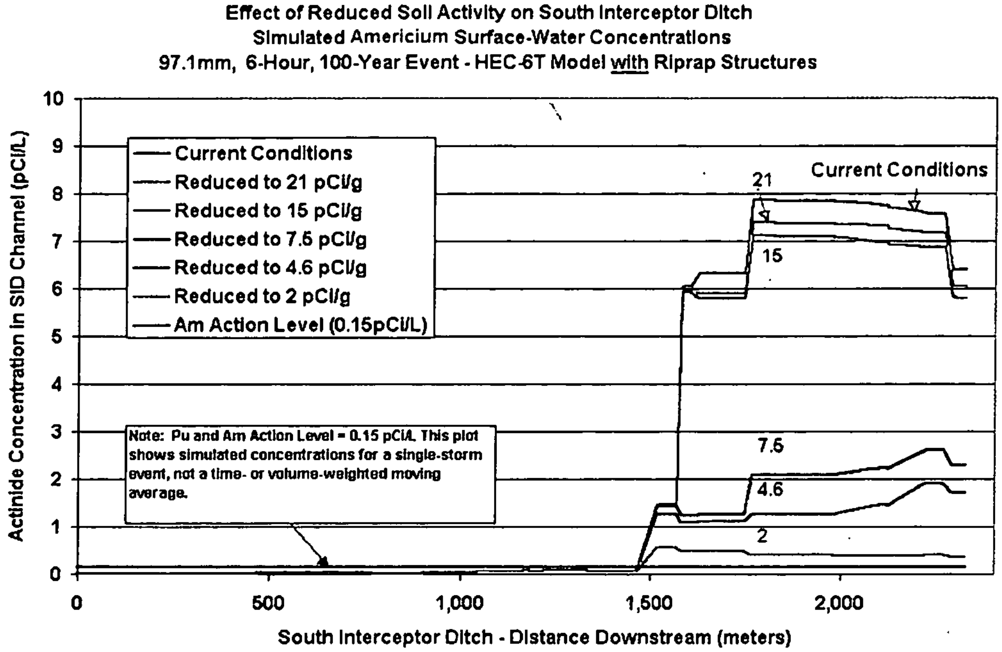

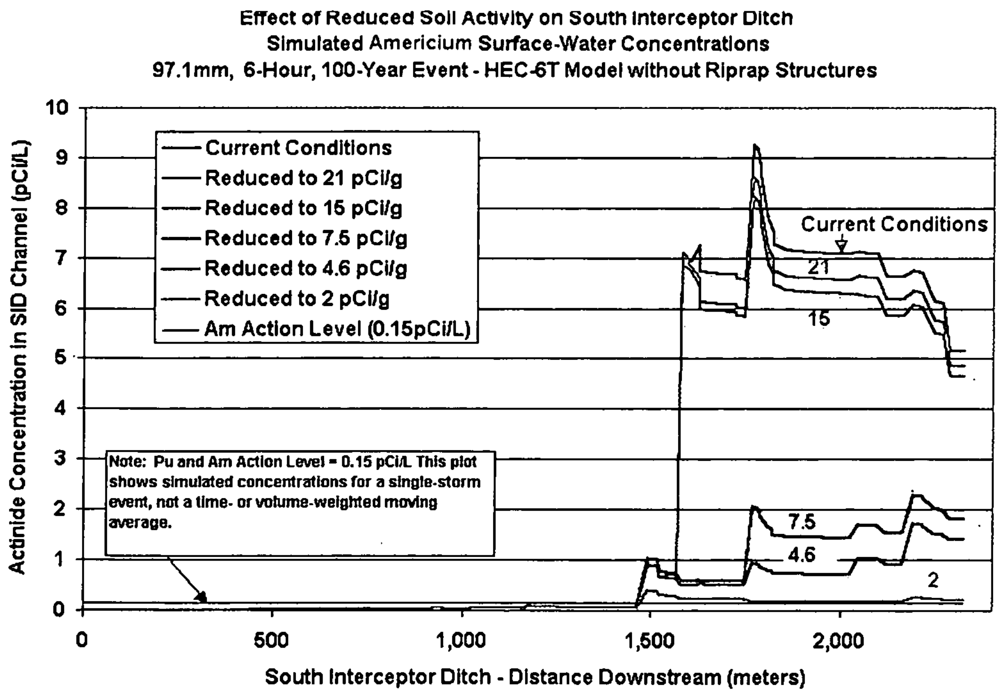

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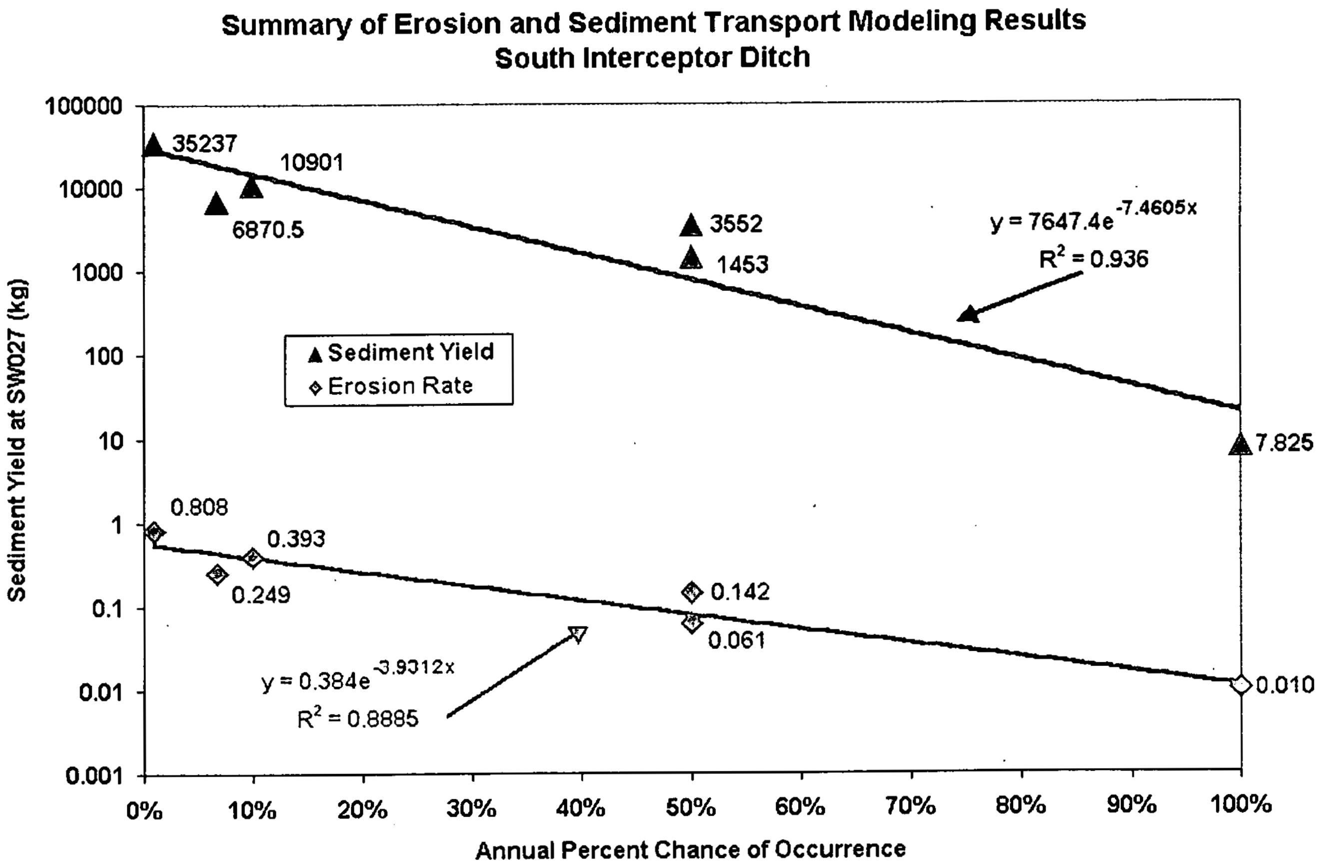

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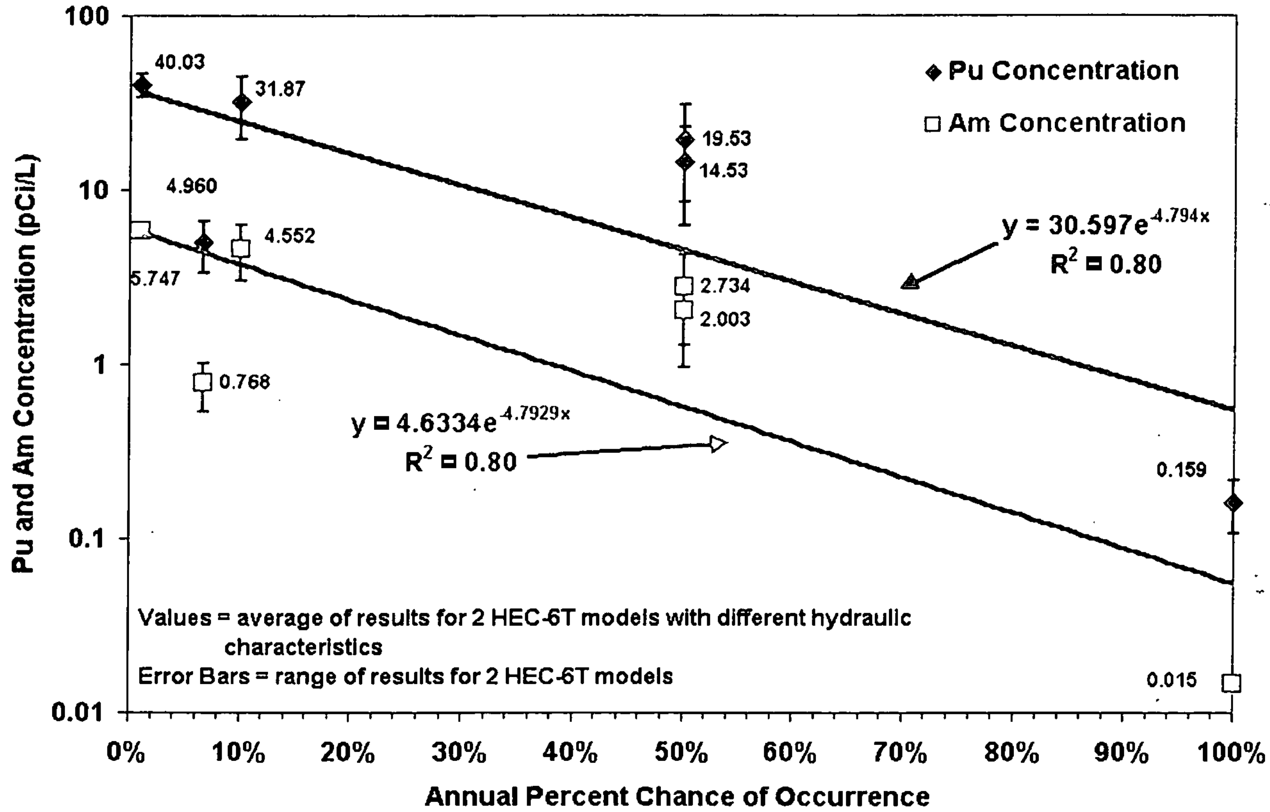

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A.1 Introduction

Several activities were undertaken in fiscal year 1998 (FY98) and FY99 to provide data for calibration of the Watershed Erosion Prediction Project (WEPP) model to Rocky Flats Environmental Technology Site (RFETS or Site) conditions, including the following:

- Soil and sediment sampling in the Walnut Creek and Woman Creek watersheds (RMRS, 1998d);
- Characterization of water-stable aggregates and of actinide distribution on aggregates in Site soils (RMRS, 1998d);
- Loading analysis for Walnut and Woman Creeks (RMRS, 1998c);
- Compilation of Site vegetation data (Table A-1 through Table A-4);
- Compilation of Site soils data (Table E-2 on CD-ROM provided with this report, Table A-5 through Table A-7);
- Compilation of Site meteorological data (Table E-1 on CD-ROM);
- Preliminary calibration of the WEPP model for the South Interceptor Ditch (SID) (RMRS, 1998e);
- Update of spatial analysis of plutonium (Pu-239/240) and americium (Am-241) distributions in surface soils (Appendix B);
- Observation of rain simulation experiments in June 1999 and use of results in calibration of the WEPP model; and
- Surface water monitoring in Site rangeland sub-basins.

A.2 Review of FY98 Preliminary Report

The results for the SID reported in the FY98 Preliminary Report on Soil Erosion/Surface Water Sediment Transport Modeling for the Actinide Migration Study at the Rocky Flats Environmental Technology Site (RMRS, 1998e) were produced using the WEPP model in the watershed mode. Runoff and soil yield estimates were made for the entire watershed, including the SID channels. The watershed component of the WEPP model was reviewed for the Site, and the following limitations of this component were identified: 1) problems in computing channel flows when an upstream, adjacent channel segment has little or no runoff input to the channel; 2) limitation to 30 hillslope and channel components; and 3) difficulties in modeling certain bed features, such as riprap drop structures, impoundments, and diversion structures. Other limitations in the use of the watershed component of WEPP are documented by Baffaut et al. (1997).

The HEC-6T model (Thomas, 1997) was chosen as the most current generation of surface water models appropriate for use with small drainages (refer to Section 5 of the main report and Appendix C).

The FY98 report (RMRS, 1998e) documented that the WEPP model produces realistic erosion estimates for Site climatic, vegetation, and soil conditions. Erosion was predicted to be greatest on disturbed and/or steeply sloped areas, with deposition on flatter and/or well-vegetated areas. Results indicated that disturbed areas, such as gravel or unimproved roads, have the largest erosion rates (tons per hectare [T/ha] or tons per acre [t/ac]).

The estimated total sediment delivery at the outlet of the SID was 4,700 kilograms (kg) (10,340 pounds [lbs])of soil for 1995 or 0.074 T/ha (0.033 t/ac) of soil per year, which compared well with the 1995 monitoring data for the SID outlet, but runoff was underestimated by a factor of 10. Although runoff was underestimated, the results were consistent with field observations by Site surface water monitoring personnel, indicating that only large storm events, or normal events occurring with high antecedent moisture conditions, produce runoff on the vegetated, undisturbed areas of the Site. Zika (1996) also discussed the same runoff characteristics for Site rainfall simulation experiments conducted near the 903 Pad in the SID watershed.

The model must correctly represent the hillslope hydrology, soil detachment and sediment transport to make meaningful predictions over a wide range of meteorological conditions. The model was recalibrated to achieve these results.

A.3 Erosion Model Parameter Sensitivity Analysis

A sensitivity analysis was conducted for a selection of input parameters used in the erosion model. This was not designed to be a statistical study of the parameters' behaviors, but rather a determination of how they effect variability in the two output parameters of greatest interest - runoff and sediment yield - at values centered around those chosen in the calibration. More extensive WEPP sensitivity analyses have been performed and are briefly reviewed below.

Analyses of the sensitivity of WEPP output parameters (e.g., runoff and sediment yield) to input parameters have been conducted on an extensive range of soil, vegetation, topographic, and climatic conditions (Nearing et al., 1989; Nearing et al., 1990; Tiscareno-Lopez et al., 1993; Risse et al., 1994, Flanagan et al., 1995). Table A-8 shows the sensitivity of input parameters for the plant management file as reported by Flanagan et al. (1995). However, results obtained for the sensitivity analysis for the Site WEPP model do not agree with all of the results reported by Flanagan et al. (Table A-9). For example, while Flanagan et al. indicated model sensitivity to the following parameters, no sensitivity was evident for Site WEPP model parameters root10 (root biomass in the top 10 centimeters [cm]), rootf (fraction of live and dead roots from maximum at start of year), and rokr (rill rock surface cover). It is unclear why this discrepancy exists.

A.3.1 Review of Previous Sensitivity Analyses

In the previous studies discussed below, runoff and erosion output have been found to be most sensitive to parameters that describe soil properties (e.g., hydraulic conductivity, texture, interrill and rill erodibility, critical shear stress, and random roughness) or surface cover (e.g., interrill cover, rill cover, and canopy cover). On short, gentle slopes, the interrill erodibility and interrill surface cover were very important. On longer and steeper slopes, input parameters relating to rill soil detachment and transport, such as rill erodibility, rill surface cover, and critical shear stress, were found to be most sensitive. Soil texture is also important and relates to the hydraulic friction factors within the model. Output was more sensitive to hydraulic conductivity for shorter, less intense storms and less sensitive for larger storms. Several factors had little effect on runoff and erosion, including canopy height, peak rainfall intensity, rill spacing and width (Nearing et al., 1990).

Sensitivity studies for the Walnut Gulch Experimental Watershed in Arizona found that the soil interrill and rill erodibility, hydraulic conductivity, standing live biomass, and rainfall characteristics, such as depth, duration, and normalized peak rainfall intensity, were sensitive parameters (Tiscareno-Lopez et al., 1993).

Risse et al. (1994) emphasized the importance of calibrating the hydraulic conductivity parameter to the study site rather than estimating it based on other properties. Using the proposed calibration procedure, Risse et al. found that all of the measured hydraulic conductivities were much higher than the calibrated values. The effective hydraulic conductivity (measured during natural rainfall) is generally estimated as 2 to 10 times less than the saturated hydraulic conductivity measured with an infiltrometer (Dunne and Leopold, 1978). This proved to be true for the Site soils.

Baffaut et al. (1998) conducted a study at sites with soil erosion study plots to determine and analyze the frequency distributions of daily soil loss and to determine whether WEPP duplicated the measured event results. The analysis of frequency curves allowed an estimate of how much soil loss occurred during the small, frequent events in comparison to the large, rare events. Baffaut et al. used the log-Pearson Type-III distribution to develop a series of empirical probability distributions for the event return period and plotted the distribution versus the daily soil loss for both the measured events and WEPP simulations. The WEPP parameters were adjusted until both data sets fell within a 95 percent confidence interval. The results of the study showed that all estimated soil loss values were sensitive to the interrill erodibility parameter. This agrees with the studies cited previously for short, gentle slopes. For large erosion events, the interrill erosion was proportionally less important and sediment yield estimates were sensitive to the rill erodibility parameter, with less sensitivity to the interrill erodibility parameter. These findings are consistent with the findings of this report and the fact that when overland flow shear stress is less than the critical value for a given soil, no rill erosion occurs and the rill erodibility is not important. In the Baffaut study, calibration was achieved by adjusting the rill erodibility parameter when the estimated values of soil loss for large storms did not fit the measured distribution and the values for small storms did. Adjusting the critical shear stress controlled the magnitude of soil loss for large events.

A.3.2 Site Model Sensitivity Analysis

Model sensitivity was determined for selected plant and soil input parameters (Table A-9 and Table A-10). The analysis was run using the plant and soil files developed for the final calibration of the model to the rainfall simulator plot results (Section A.7.2). Values of the derived parameters used in this analysis are centered around the calibrated values to demonstrate the sensitivity of runoff and sediment yield near the selected values. The bold entries in Table A-9 and Table A-10 are those used in the model calibration. Both 10-meter and 50-meter plots with a 9 percent slope were evaluated. Values for runoff and sediment yield were estimated using the climate file for the 100-year continuous simulations and a 50-year simulation. Analyses of the model sensitivity to slope length and slope are reported in Section A.4 and Table A-11).

A.3.2.1 Plant Parameters

Results are presented in Table A-9 for eleven plant parameters: 1) maximum live standing biomass (plive); 2) canopy cover (cancov); 3) roots in the top 10 cm (4 inches) (root10); 4) percentage of live and dead roots at the start of the year (rootf); 5) initial random roughness of the soil surface (rrough); 6) interrill litter surface cover (resi); 7) interrill basal cover (basi); 8) interrill rock cover (roki);) 9) rill litter surface cover (resr); 10) rill basal cover (basr); and 11) rill rock cover (rokr).

A.3.2.1.1 Runoff

Results of the plant sensitivity analysis show that runoff is insensitive to root10, rootf, roki, and rokr over the ranges of values tested (Table A-9). Runoff increased with increasing values for one parameter, basr. The magnitude of the increase over range of values tested was about 1 percent for the 10 m plot and 3 percent for the 50 m plot. The rill and interrill parameters interact in the model. The 100-year simulation average values for interrril and rill cover in Table A-9 clearly show this interaction. Apparently runoff is more sensitive to the decrease in interrill cover with increasing basr, than to the resulting increase in basal cover.

Six parameters decreased runoff over range of values tested for both slope lengths in the order basi <cancov < resr < rrough < resi < plive. The range of the change in predicted runoff over the range of values tested was larger for the parameter causing a decrease in runoff, ranging from 1 percent to 15 percent for the 10 m plot and from 2 percent to 17 percent for the 50 m plot. Runoff depth was consistently lower for the 50 m plot, and runoff was slightly more sensitive to the parameters tested. This analysis shows that, in the range of the values chosen in the calibration of the vegetation parameters, a change in any one of these parameters does not significantly affect the long-term estimate of runoff. It is beyond the scope of this analysis to investigate the effect of varying the values of multiple parameters simultaneously.

A.3.2.2 Sediment Yield

Sediment yield was much more sensitive to the tested plant parameters than runoff. Once again root10 and rootf had no effect over the range tested for both plot lengths. There was no effect due to rokr on the short slope and a 1 percent decrease on the longer slope. The value of 0.01 (1 percent) was reported for the EMSP rainfall simulation study and was used to calibrate the model to the rain simulator plot data (Section A.7). Several of the management files for plant communities in the Site model have higher values of rokr, based on Site data and field observations.

Two parameters, rootf and root10, had no effect on erosion (Table A-9). Only one parameter, basr (rill basal cover), increased sediment yield at higher values. The results show that basr increases erosion over the range studied, by 44 percent on the 10-meter plot and by 27 percent on the 50-meter plot. The greater increase in erosion on the shorter plot indicates that it is the interaction of the rill and interrill parameters in WEPP (see discussion in Section A.3.2.1.1) that caused the sediment yields to rise. Raising the value for basr results in a an increase in the total rill cover and a reduction in the total interrill cover calculated by the model over the length of the simulation. The erosion algorithms in the model are more sensitive to the reduction in the interrill cover than the the increase in rill cover.

The remaining parameters decreased erosion at higher values over the range studied in the order rrough < resr < basi < roki < cancov < resi ≤ plive on the 10 m plot. The decrease in erosion ranged from 7 to 98 percent. Results for the 50 m plot were similar, with sediment yield reductions ranging from 19 to 95 percent over the range tested. However, the sensitivity of the model to the parameters basi and resr were reversed (basi < resr) compared to the shorter plot due to the greater contribution of rill processes to the total sediment yield on the 50-m slope. The maximum standing biomass (plive) has the greatest effect on both runoff and erosion of the tested parameters. The values of plive used in the plant management files for the Site model were based on Site plant communities data (DOE, 1995c; Kaiser-Hill, 1997). The results indicate that using average values for plive for the plant communities may have a significant smoothing effect on estimated erosion in some areas on Site with high natural variability.

Table A- 9 also shows the effect that the six interrill and rill cover parameters have on 100-year average percent total interrill and rill cover. Rock cover has a linear effect on 100-year average values for the same area cover (interrill or rill). An increase in resi or basi simultaneously increases average values for total interrill cover and decreases the average values of rill cover. An increase in the rill parameters, resr or basr, has a similar affect, but in reverse, increasing average values for total rill cover and decreases the average values of interrill cover. As discussed above, it is the interaction of the interrill and rill litter cover parameters on the long term averages of interrill and rill cover that has a significant affect on erosion and sediment

A.3.2.2 Soil Parameters

Seven soil parameters used in the calibration were examined for effects on runoff and erosion: 1) interrill erodibility (Ki); 2) rill erodibility (Kr); critical shear stress (τ_c); 4) hydraulic conductivity (Ke); 5) percent soil saturation (Sat); 6) percent clay in the top layer of the soil; and 7) percent sand in the top layer of the soil (Table A-10). Both 10-meter and 50-meter plots at 9 percent slope were used. The same 50-year simulation used for the plant parameters was used for the soil parameters.

A.3.2.2.1 Runoff

The three parameters directly related to erodibility of the soil, Ki, Kr and τ_c, have no effect on runoff (Table A-10). The hydraulic conductivity (the rate at which rainfall infiltrates into the soil in millimeters per hour [mm/hr]) has a very large influence on runoff and also on

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erosion. As the Ke increases, more rainfall infiltrates into the soil and less is available for runoff. Runoff varies by 16 to 28 percent on the 10-m plot and 21 to 24 percent on the longer plot at ± 20 percent of the simulation plot (10 m) calibration value of 15.3 mm/hr. The initial percent saturation of the soil (the volume of water in the soil pores divided by the total volume of the pore space [voids] of the soil) has no effect on long-term estimates of runoff or erosion. This parameter responds to meteorological conditions, rising during wet periods and falling during dry periods. For this reason, it is an important parameter for single storm simulations, like those used in conjunction with the HEC-6T modeling.

The changes in the percentages of sand and clay have somewhat unexpected effects on runoff. Holding one constant and varying the other increases runoff for both but by about double the amount when the percent sand is increased compared to an increase in clay. When percent clay is raised from 12 to 42 percent, the runoff increases by 5 mm (66%) on the 10-m plot and by 3.7 mm (68%) on the 50-m plot. An increase in sand, however, from 26 to 66 percent increases runoff by 10.7 mm (157%) on the short plot and by 7 mm (127%) on the longer plot. When both are varied together, the effect is also large. The result for clay is expected. Increasing the clay content while holding sand constant decreases the silt content and more runoff would be expected. The much greater increase in runoff with increasing sand content is unexpected and is likely related to factors that are calculated by the model for the infiltration algorithm (e.g., bulk density, porosity, soil moisture and others).

When both clay and sand are varied together over the same range of values and the sum of the two is held constant (e.g. 27% [clay] + 46% [sand] = 73% total) the effects are not as pronounced. The runoff estimates for the 10-m plot are much more sensitive to this change in parameter values than the 50-m plot estimates. Runoff increased by 24 percent on the shorter plot over the range of values tested, while the change for the 50-m plot was only 4 percent. The reason for the effect of slope length on the sensitivity of the model to the simultaneous change in clay and sand content may be related to a combination of factors in the algorithms that calculate infiltration and overland flow hydraulics.

In the range of the values used for the side-slope soil (27 % clay, 46% sand), a change of ± 20 percent in the clay content changes runoff by only ± 6 to 9 percent for both plot lengths. A change of ± 25 percent in the sand content alters the runoff by 9 to 18 percent, with the greatest influence on the shorter plot (Table A-10). A simultaneous change of about ± 25 percent in the values the two parameters alters runoff by ± 3 to 12 percent. Again, the greatest effect is on the estimate for the 10-m plot. This demonstrates that by using average values for sand and clay in the soil files, the effects of the spatial variability of these parameters across the Site landscape are smoothed and may influence the accuracy runoff estimates in areas of high soil textural variability by up to ± 25 percent or more.

The confounding factor in these analyses is that the Ke is held constant. In situ, increasing clay content generally decreases the hydraulic conductivity, while increasing sand content will usually increase the hydraulic conductivity. It appears that when Ke is constant, there is some unexpected interaction among algorithms used by the model to compute runoff. These results demonstrate the interaction of factors used in the complex model algorithms used for estimating runoff.

A.3.2.2.2 Sediment Yield

The seven soil parameters tested for sensitivity can be divided into two groups by the way they affect sediment yields. One group affects erosion without affecting runoff, and the other group affects runoff, which in turn affects erosion. Three parameters, Ki, Kr, and τ_c, directly affect erosion without changing runoff; each has a large influence erosion. Three parameters, Ke, percent clay, and percent sand, influence sediment yield through their relationship to runoff. The initial value of percent soil saturation does not influence the long-term average estimated erosion, but it is important in the single storm mode of WEPP.

The relative amounts of interrill and rill erosion resulting from the calibrated parameters (results in **bold**) can be calculated by comparing the results of decreasing Kr or increasing τ_c to where they no longer influence the erosion estimate (Table A-10). The estimated erosion due to rill processes is 0.003 T/ha (0.001 t/ac) or 2.7 percent of the total 50-year average for the 10-m plot. The proportion of rill erosion increases on the 50-m plot (a factor that complicated the calibration of the model [see Sections A.3.2.3 and A.7]) to 0.018 T/ha (0.008 t/ac) or 18.5 percent of the total estimated erosion. These results conform to expectations of increasing rill erosion with increasing slope length.

Changes in the clay and sand content have relatively less effect on estimated erosion than on runoff. A ± 20 percent change in clay from the average value, while holding sand constant, results in a – 6 percent to +53 percent change in estimated erosion and is similar on both plot lengths. The greatest effect occurs with an increase in clay content. Varying the sand content has less effect. A ± 25 percent change in sand content results in a –12 to +17 percent change in estimated erosion. Varying the two simultaneously has a similar impact on estimated erosion as varying the sand alone. These results indicate that using the average value for soil texture will have a smoothing effect on erosion estimates. The greatest local impacts on estimated erosion

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due to variations in sand and clay contents across the Site will occur where clay content is underestimated and sand content is near the average.

There appears to be an anomaly in the data for both %sand and %clay/%sand. Estimated erosion at the calibrated value is less than that for both the immediately higher and lower parameter value on the 10-m plot. This was not true for the 50-m plot. The result was checked and rerun several times; results were always equivalent and are valid.

A.3.2.3 Effects of Slope Length and Number of Overland Flow Elements

The effects of slope length on runoff and, thus, erosion were mentioned in Section A.3.2.2. Table A-11 shows the results of simulations run to observe the effect of slope length and number of Overland Flow Elements (OFEs) on estimated runoff and erosion. They were performed in the single storm mode of WEPP using the 100-year, 6-hour, and 97.1-mm (3.8 inches) event. Slope length was varied from 10 to 320 meters; the slope was 9 percent. All parameters except slope length and number of OFEs were held constant. Estimated runoff and sediment leaving the bottom of the hillslope are in **bold**.

A.3.2.3.1 Runoff

The data in Table A-11 show that slope length from 10 to 80-m and number of OFEs (1 or 8) had no effect on estimated runoff. A second set of simulations were performed using multiples of 40 m. The estimated runoff for the 40-m long hillslope matched that for the 10 to 80-m hillslopes and the first 80 meters of the 8 OFE 320-m hillslope. The estimated runoff depth for both 320-meter hillslopes (1 or 8 OFEs) was only 39 percent of that for the 10 to 80-m hillslopes. This illustrates an artifact of the model that makes the calibration of long hillslopes difficult and, for hillslopes with lengths greater than about 100 m, could add uncertainty of up to 50 percent to the estimated runoff results, with uncertainty increasing with slope length.

The authors of the WEPP model code were contacted. They indicated that they were not aware of this artifact. The authors evaluated the artifact using input files provided by the project and other data. To date, the matter remains unresolved.

The discovery of this artifact of the model algorithms explained some of the problems that were encountered during attempts to calibrate the model. A method was developed by the AME erosion modeling team to minimize the effect of slope length on estimated runoff by adjusting the Ke with slope length. This compensates for the underestimation of runoff by the model and controls the uncertainty on longer hillslopes due to the model algorithms. The last two hillslopes in Table A-11 demonstrate that by lowering the Ke for the hillslope (1 OFE) or for the down-slope OFEs, uncertainty in estimated runoff due to slope length can be reduced to less than 1 percent based on this analysis. Furthermore, the uniformity of the watershed results (see report) indicates that the method developed by the Site were successful in minimizing the effects of slope length on runoff estimates.

A.3.2.3.2 Sediment Yield

Estimated erosion rates on the 10 to 80 m hillslopes were related to hillslope length, increasing with slope length by 34 percent while runoff was constant. This is due to increasing rill effect with slope length. The erosion rates estimated for the 320-m hillslope varied from about 25 percent less than those for the 80-m slope length (1 or 8 OFE) for the 1 OFE hillslope to about 13 percent greater on the 8 OFE hillslope, when the Ke was held constant at the value used for the 10 to 80-m hillslopes. In this case, the effect of slope length on the sediment yields was confounded by the decrease in runoff as a result of the artifact discussed above. The estimated erosion rates on these hillslopes were sensitive to the number of OFEs, increasing by 53 percent on the 8 OFE hillslope, although the estimated runoff was unresponsive.

The hillslopes with the Ke parameter adjusted for slope length show the response of estimated erosion to increased runoff. Estimated erosion yields increase by about 140 percent due to an increase in runoff of 150 percent to values nearly identical to the 10 to 80-m slopes. The increase is due to rill effects on the longer hillslopes. The erosion estimates for the 320-m hillslopes were only slightly sensitive (± 2 %)to the number of OFEs when the Ke slope length adjustment method was used. The adjustment of Ke to produce more uniform runoff estimates also has the advantage of stabilizing erosion estimates regardless of the number of OFEs.

A.3.2.3.3 Effects of Slope Steepness

Table A-12 shows the results of three simulations that demonstrate the effect of slope steepness on runoff estimates when all other parameters are held constant. The simulations were done in the continuous mode with six 60-mm, rain simulator storms seeded into the climate data. Varying the slope steepness from 4 to 20 percent has no significant effect on runoff. This is the expected result as there is not a slope steepness-runoff parameter modification procedure within the WEPP model.

A.4 Meteorological Data Used for Calibration of the WEPP Model

The Site receives an annual average of 368 mm (14.5 inches) of precipitation (DOE, 1995a). Figure A-2 shows the distribution of precipitation during the year at the Site. April and May are the wettest months, with the majority of precipitation received from March to

September. Site meteorological stations are shown on Figure A-3. Precipitation is fairly evenly distributed across the site on average Figure A-4. Much of the summer precipitation is received from thunderstorms and the rainfall pattern may be quite variable for any single storm.

Site precipitation data for the years 1993 through 1999 (Figure A-4 and Figure A-5) precipitation data from 1995 to 1998 were used to check the calibration to the rainfall simulator plots. These data were also inserted in the 100-year climate file, because the most reliable surface water data for the Site are for that period (RMRS, 1998c). These years also represent a range of precipitation events, with 1995 being a wet year (550 mm, 21.7 inches); 1996 and 1998 average years (364 mm, 14.3 inches); and 1997 an intermediate year (446 mm, 17.6 inches). The Site meteorological data for 1993 to 1998 are presented in Table E-1 on the CD-ROM.

Estimates of precipitation amounts for 6-hour design storms with return periods of 2, 10, and 100 years and a 2-hour storm with a 2-year return period were taken from the Rocky Flats Plant Drainage and Flood Control Master Plan (EG&G, 1992b). Two storms with durations of 11.5 hours were also modeled: the May 17, 1995, event with 74.9 mm of precipitation and a less intense storm with 35 mm of precipitation. Erosion and runoff for these events were modeled with WEPP. The results for these storms were used for the sediment and actinide transport modeling. Actinide mobility maps were also created from the modeling results for the design storm events.

The 100-year, long-term estimates for runoff and erosion were made using a 100-year climate file generated by the CLIGEN weather generator (Nicks, 1985). The Site meteorological record was not of sufficient length to be used with CLIGEN. The length of the period of record is very important in generating meteorological statistics. Station data for a large selection of Colorado sites are included with the WEPP model. Data from the Fort Collins (Colorado State University) weather station was used as the input for CLIGEN. The Fort Collins station data were selected over the Boulder station, because it had a period of record of 92 years, compared to 49 years for Boulder. Fort Collins was also chosen because it is situated along the front range with a climate very similar to the Site's average annual precipitation. Return periods, estimated using a log-Pearson Type III distribution (Beard, 1964) for events in the 100-year weather file, including the 1995 to 1998 Site data, are shown in Figure A-6.

The 1995 to 1998 Site meteorological data were inserted into the CLIGEN-generated 100-year weather file as years 15 to 18. Data for estimated runoff and erosion for years 15 to 18 (1995-1998) were extracted from the WEPP output files. These data were used for calibration to Site surface water runoff and sediment yield data.

A.5 Site Soils Data for WEPP Erosion Modeling

The soil series displayed on Figure 4 of the main report were described and mapped by the Soil Conservation Service (SCS, 1980). The soil data used for determining the soil-input parameters for WEPP are shown in Table E-2 on the CD-ROM, and sampling locations are shown on Figure 4. The data were derived from three sources: the Operable Unit 2 RCRA Facility Investigation (RFI)/ Remedial Investigation (RI) (DOE, 1995b); the *Characterization of Physical and Hydraulic Properties of Surficial Materials and Groundwater/Surface Water Interaction Study at Rocky Flats Plant* (Fedor and Werner, 1993); and data provided by the Colorado Department of Public Health and the Environment. The data were grouped in three ways; by soil series; by textural class (e.g., sandy loam); and by position on the landscape (e.g., at the top of the pediments). The evaluation of the Site soil characteristics, including texture (percent sand, silt, and clay), hydraulic conductivity, bulk density, and percent organic matter, determined that soil variability was so large that the most representative method of grouping soils was by position on the landscape (Table A-5 and Table A-6). Grouping soils by soil series was unnecessarily complex for the modeling. Soils data were grouped into three categories for the WEPP model (refer to Figure 6 of the main report for soil series locations):

Top-slope, a sandy loam which includes areas classified as the Flatirons series and the Nederland series, is located on the top of the pediments and extends about 61 meters (200 ft) down-slope beyond the pediment edge;

Side-slope, a sandy clay loam, which includes areas classified as the Denver-Kutch-Midway complex, the Leyden-Primen-Standley complex, the Willowman-Leyden association, and scattered areas of Englman and Nunn series, is located on the gentle to steep slopes that extend from the pediment to drainages; and

Toe-slope, a clay loam, which includes areas classified as Standley-Nunn association, Haverson, Nunn, Englewood, and Valmont series, are the bottom lands along the drainages (Table A-5). These soil series exist adjacent to each other; grading from one to another.

Specific soil parameters were estimated by using the average values for the three soil categories described above, and WEPP input soil files were created Table A-6 gives descriptive statistics for several soil characteristics, from Site-specific surface soil data (Table E-3), grouped by the landscape position at which the soil samples were taken.

The data in Table A-6 show that mean hydraulic conductivity, as measured with a tension infiltrometer (at 15 cm of tension), has a very high degree of variability in each soil grouping. Although the standard deviations for hydraulic conductivity are very high for all soils positions,

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they overlap for all three categories. The coefficients of variation (standard deviation divided by the mean) are quite similar for the three positions, indicating a similar degree of variability. The values compare well with those determined by Zika (1996) using a less comprehensive data set. Although there is little difference between the side-slope and toe-slope soils in the variables shown in Table A-6, both categories were retained to better define landscape regions. The mean hydraulic conductivity values were used as the starting point for calibration of the WEPP input values for Ke. The soil texture, organic matter, and CEC parameters were held constant during the modeling. The use of the mean Ke values resulted in underestimated runoff (see Sections A.3 and A.6). Calibration of the Ke parameter is discussed in more detail below. Soil input files were also created to represent runoff and erosion characteristics of paved surfaces, improved roads (modeled as "clay"), and unimproved roads (modeled as sandy loam). The parameters used in the soil input files are shown in Table A-7.

A.6 Calibration of the WEPP Model Plant Module

The WEPP model produces detailed output on plant growth, root, and residue parameters for user-defined plant communities/habitats. Sixteen habitat types found in the watersheds and used in the modeling are shown in Table A-1 and in 7 of the main report. Site-specific vegetation and habitat data were compiled from the Site Vegetation Report, Terrestrial Vegetation Survey (1993-1995) for the Rocky Flats Environmental Technology Site (Kaiser-Hill, 1997); the Rocky Flats Environmental Technology Site Environmental Monitoring Program, 1995 Annual Report (DOE, 1995c); and the Baseline Biological Characterization of the Terrestrial and Aquatic Habitats at Rocky Flats Plant (DOE, 1992a). Table A-2 documents the process of choosing the measured and derived plant parameters.

Two types of plant files are needed as input for the model. The first, is the initial conditions file which contains values for parameters including snow depth, residues, and various types of ground cover at the start of the simulation (Table A-3). The second is the plant management file which describes the plant growth characteristics of a particular plant community (e.g. mixed mesic grassland) or habitat (improved gravel road) (Table A-4).

An examination of the plant growth, root growth, and residue output from the 100-year simulations run for the FY98 report revealed anomalous patterns that did not conform to the Site observations. A number of plant input parameters that are not Site-specific or for which there are no Site data were used to calibrate the vegetation output. These include the canopy height coefficient, leaf area index coefficient, plant area coefficient, residue mass coefficient, root mass coefficient, and fraction of live and dead roots (Flanagan and Nearing, 1995). The plant

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parameters were calibrated so that the 100-year averages of important cover parameters agreed with the averages of Site data for each plant community (Table A-13). Plant growth patterns for some dominant habitat types are shown in Figure A-7 through Figure A-13. The calibration of the plant inputs had the added benefit of increasing runoff, which was being underestimated previously.

The management files for the improved gravel roads were set to grow no vegetation during the simulations (Figure A-8). The unimproved road vegetation files were calibrated to have less cover than the surrounding area to account for traffic effects. There was also a group of hillslopes that were modeled as grazed, off-Site, at the western end of the Woman Creek watershed. These hillslopes were modeled as being grazed from May through October, at an average density of one head per 5 ha (12 ac.). Grazing reduces cover and increases erosion.

Another calibration was required for the single event runs, because even in the single storm mode the input parameters for cover are not the values output by WEPP. The vegetation and soil cover input data were adjusted for the single storm mode runs. The sensitive soil cover and vegetation cover parameters were adjusted to within one standard deviation of the WEPP 100-year simulation average values for the single storm modeling (Table A-14). The method described standardized the WEPP-vegetation growth and soil cover for all of the events modeled.

A.7 Calibration of WEPP Model Runoff and Erosion Rates for the Site

A.7.1 Sufficiency of Stream Flow and Suspended Solids Data

The AME modeling project compiled the available stream gaging and runoff monitoring data for Site stream gages (Tables E-4 and Table E-5 on CD-ROM) to perform an analysis of sediment and actinide loads in streams (RMRS, 1998c). Descriptions and dates of operation of the Site gaging stations are given in Table A-15. Data in the Loading Analysis for Actinide Migration Studies at RFETS (RMRS, 1998c) report include runoff coefficients (i.e., the ratio of runoff to rainfall), estimated watershed erosion rates, sediment yields, and actinide yields for the Woman Creek and Walnut Creek watersheds. These data provide a basis for comparison of WEPP-estimated runoff and erosion rates, and the results of the sediment transport modeling (Appendix C), to measured runoff and sediment loads in the streams.

Before the CSU/EMSP rain simulation data became available, the erosion modeling project attempted to calibrate WEPP to surface water gaging station data. The data for TSS are sparse and not collected routinely, and there are more monitoring data for flow than for TSS.

The runoff and TSS data shown in Figure A-14 through Figure A-29 include all available data for gaging stations with more than two TSS analyses and accompanying flow measurements. Most of the water samples were collected for small events, and the range of the data is limited. The largest event represented is the May 17, 1995, storm. However, much of the flow data for this event are estimated based on gage data collected before the flow recorders stopped functioning due to flooding and power loss. This adds considerable uncertainty to the flow and TSS data that were collected for the largest flood recorded at the Site.

The limitations of the monitoring data presented above highlights the uncertainty created by use of the present database for calibrating the erosion model or the sediment transport model to Site conditions. Modification of existing surface water monitoring programs are being evaluated to enable data collection that will enhance the models' power for making management decisions. Two gaging stations were installed specifically for this study (GS41 and GS42 in Figure A-3), and data for these stations are shown in Table A-16.

The use of stream yield data introduced uncontrolled variables into the calibration analysis, including: determination of baseflow, channel infiltration, subsurface storm-flow, ungaged inflows, and channel and bank erosion. Until the rainfall simulation data became available for calibration of the WEPP model, runoff was calculated for the gaging stations by: a) subtracting the baseflow, measured prior to the start of the precipitation events from the stream flow occurring during the precipitation runoff, and by comparing the calculated runoff to the runoff predicted by WEPP. This adds unquantified uncertainty to the calibration. The use of the CSU/EMSP rain simulation data for calibration reduced uncertainty and produced reasonable estimates of runoff and erosion that compared favorably with the monitoring data.

A.7.2 Rainfall Simulation Studies

The WEPP model was developed using data from the CSU/EMSP rain simulation experiments in which a measured quantity of water is delivered to plots of known characteristics by a rotating boom rainfall simulator. The machine has ten 7.6-m booms that radiate from a center-pivot at a height of 3 m (Figure A-30). The simulator moves in a circular path and applies rainfall intensities of about 65 mm/hr or 130mm/hr with a drop-size distribution similar to natural rainfall. The energy of rainfall impact is about 80 percent of natural rainfall (Simanton et al., 1991).

The rainfall is applied to small plots, 3.05 m by 10.67 m (10 ft by 35 ft), that are surrounded by metal edging that is pushed into the soil so that runoff can only exit the plot through a specially designed flume at the downslope end of the plot. The runoff passing through the flume is measured for quantity and rate of flow. Vegetation and cover measurements are taken for parameters used in the WEPP model. Samples of the runoff water are collected as it leaves the flume, and samples are taken for determination of entrained sediment and any other constituents that may be of interest to the researchers. Soil samples are taken to determine soil moisture content, and rain gages are set out to record the amount of water applied. The process is repeated three times over two days to simulate dry, wet, and very wet antecedent soil moisture conditions (Simanton et al., 1985). The rainfall simulation data are representative of high intensity, short duration events, which have a low probability of recurrence (i.e., high return period). Consequently, WEPP was first developed and validated with simulated large events (Wilcox et al., 1992; Simanton et al., 1991; and Nearing et al., 1989) and later with studies using natural rainfall data (Savabi et al., 1995; Zhang et al., 1996; Liu et al., 1997; Buffaut et al., 1998).

Rainfall simulation studies conducted in the former Operable Unit No. 2 area of the Site, by Zika (1996) in 1994 and 1995, produced little or no runoff during dry simulation runs. The soils in the two areas used for the simulations, soil pits 2 and 3, are sandy loams of the Flatirons-Nederland association, designated as "top-slope" soils for the current study, and have high infiltration rates and hydraulic conductivities (DOE, 1995b). Zika used the Ke and the initial soil saturation parameters in WEPP to calibrate the model for runoff. Zika's calibrated Ke from the simulation data varied from 16 mm/hr to 30 mm/hr (Zika, 1996). Runoff tended to occur when initial soil saturation was above 54 percent. Zika's calibrated Ke of 16 mm/hr is very similar to the Ke of 15.3 calibrated to the EMSP rainfall simulation study by the AME project team. No samples of runoff solids concentration were collected for the Site rain simulation studies, so Zika's data could not be used to calibrate the WEPP model's erosion parameters. However, Zika's data were helpful for evaluating runoff characteristics.

The CSU/EMSP rainfall simulation study was conducted just south of the Site by a group lead by Tom Hakonson and Mat Johansen and funded by the U.S. Department of Energy (DOE) Headquarters under an EMSP grant. Site personnel observed the simulations. The soils are of the same types that were grouped as the side-slope soil. The investigators were very helpful to this project and offered to share their data with the Site to facilitate calibration of the WEPP model. The rainfall simulation data used for model calibration became available in December 1999.

A.7.3 Calibration of the Erosion Model Using Rainfall Simulation Data

The rainfall simulation data provided by the CSU/EMSP project were invaluable for calibration of the Site erosion model. The simulations were located on Hope Ranch, south of the Site and to the west of Indiana Avenue. The soil survey for the Golden Area (SCS, 1980) identifies the soils in the area of the simulations as Denver-Kutch and Denver-Kutch-Midway associations. These are the soil series that predominate on-Site in the areas designated as side-slope soil.

Table A-17 and Table A-18 contain the measured plant and soil cover parameters and WEPP simulation results for the rain simulator plots. Only the natural plots were used. A second series of plots had the vegetation burned to simulate the effects of a range fire. The burn results may be used for modeling range fire scenarios in the future. The area of the plots was lightly grazed up to the time of the simulation. This created some differences in the cover parameters used in the management files for the simulator model runs as compared to those used for the Site plant communities. The calibrated plant parameters are presented in Table A-3 and Table A-4. A brief description of the calibration process is provided below:

Discussions were held with Dr. Leonard Lane, the project peer reviewer and nationally recognized expert on hydrologic processes, on the calibration methodology. The measured parameters for the side-slope soil were used for the basis of the rain simulator soil file (Table A-7). Vegetation and cover parameters were calculated from the measured data and inserted into the management file developed for the mesic plant community (Table A-3, Table A-4 and Table A-13).

The vegetation file was run with the 100-year climate file and calibrated so that the 100-year average for canopy cover, and interrill and rill cover, matched well with the measured data from the rain simulator plots (Table A-13). A 60-mm/hr (2.4-inch/hr) evenly distributed event that matched the rainfall simulator application, was created and inserted into the 100-year climate file six times on days with cover output that matched the measured data. The 60-mm events were inserted during periods with no rainfall immediately preceding the event. The parameters, Ki, Kr, τ_c, and Ke were adjusted to produce runoff and erosion estimates that matched the mean values for the dry run for the rainfall simulation.

Calibration of the Ke parameter is straight forward for the 10-m plot length (see Section A.3.2.3), and runoff results were easily calibrated for the plot. Calibration of the sediment yield is more complicated due to interactions of the three parameters that control the erosion calculations, Ki, Kr, and τ_c,. Many combinations of the three parameters will duplicate the plot erosion data. The goal of the calibration is to duplicate the sediment yield value by modeling the processes that occur on the plot. WEPP models both interrill and rill erosion processes, as discussed previously. The relative contribution of each change with hillslope length (see Section A.3.2.3), interrill being dominant on short slopes (e.g., the rain simulator plots) and rill erosion becoming more dominant as slope length increases (e.g., Site hillslopes). The critical shear stress parameter, τ_c, controls the effects of the rill erodibility parameter, Kr, decreasing the influence of Kr as τ_c increases.

The calibration process began by attributing 90 percent of the plot erosion to interrill and 10 percent to rill erosion. When this calibration was transferred to the longer hillslopes, erosion was extremely overestimated. Increasing the τ_c to reduce the yields on the long hillslopes lead to underestimation on the rain simulation test plot.

Rain simulator plot files were created for different hillslope lengths so that the effect of length could be investigated. During this process, the discontinuities in runoff and sediment yield, which were discussed previously in the sensitivity analysis, were discovered by the modeling team. Discussions were initiated with the model developers, and, in the process of documenting this behavior of the model, the Ke hillslope length adjustment method that minimized the effect of slope length was created (see Section A.3.2.3). The key is to reduce Ke as slope length increases above 100 m to maintain a constant runoff coefficient (runoff divided by rainfall).

Once the Ke artifact was overcome, it was necessary to determine the ratio of interrill erosion to rill erosion on the rain simulator plot that would also give reasonable results on the Site hillslopes. This was done by gradually lowering the contribution of rill erosion to the total sediment yield and by checking the resulting parameters on long hillslopes.

Eventually, a combination of values was obtained that successfully simulated the measured rain simulator plot data and produced reasonable results when transferred to the longer Site hillslopes. The calibrated simulator parameters resulted in WEPP estimates of about 98 percent interrill and 2 percent rill erosion on the 10 m plot. These are the values in Table A-7 for the simulator and the side-slope soils. A comparison of the observed and WEPP-estimated sediment yields for the rain simulator plots is shown in Table A-18. The response of estimated interrill and rill soil loss to slope length for the calibrated model is shown in Figure A-1.

The results were then checked against a well established methodology, used in the Revised Universal Soil Loss Equation (RUSLE) erosion estimation model (discussed in Section

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4 of the main report [USDA, 1997]). One of the parameters in RUSLE is the slope length factor (L), which relates slope length to the erosion by rilling.

The L-factor is calculated using the following equation:

$$L = (\lambda/72.6)^m \qquad (1)$$

where:
L = slope length factor;
λ = slope length;
72.6 = RUSLE unit plot length in feet; and
m = variable slope-length exponent dependent on the grade of the slope

The curves in Figure A-31 are the calculated erosion for a hillslope of various lengths, up to 800 m, and a 9 percent slope, using equation (1) the m factor set for low and medium rilling rangeland soils and the WEPP predicted results for a 22.1 m (72.6 ft) slope length for the sideslope and topslope soils. The soil loss estimates for the two soils are the averages for six 60-mm events seeded into the 100-year climate file. The results for the sideslope soil show a very close approximation to the line for a soil with medium susceptability to rilling. This is likely to be an overestimate of the effects of rilling on a well vegetated rangland soil, especially on longer hiillslopes and will result in conservative estimates of erosion (USDA, 1997). Discussions in the following sections will show that although estimated soil losses are generally conservative (high), they are reasonable.

The top-slope soil was calibrated to yield less erosion and a lower percentage of rill erosion, based on the rainfall simulation results and observations of Zika (1996). The sediment yields over the interval of 10 to 800 m, were considerably less than for the sideslope soils. The results for the topslope soil show that, as calibrated, WEPP predicts a low rilling potential for the soil. Figure A-1 shows that at 800 m 53 percent of the erosion on the topslope soil is due to rilling, compared to on 86 percent on the sideslope.

The Site improved roads were calibrated using data in Elliot et al. (1994), Elliot et al. (1995) and Tysdale et al. (1997). The unimproved roads were modeled using the soil files for the type of soil in the area. The Ke was set lower to reflect compaction due to traffic, and the vegetation files were modified to represent less cover. The soil parameters for the grazed hillslopes to the west of the Site that drain to Woman Creek were modified to reflect trampling by cattle, including an increase in surface roughness (rrough) and compaction. Grazing of the vegetation was simulated by WEPP. The final validation of the calibration was to compare the estimates obtained from the 100-year simulation to values from the surface water monitoring program (Figure A-14 to Figure A-29), including data for two monitoring stations installed specifically to collect information for this study (Table A-16).

A.7.3.1 Antelope Springs Gulch (Station GS16)

Antelope Springs Gulch is a perennial stream that channels flow from Antelope Springs to Woman Creek. Gaging station GS16 was located just downstream of an improved gravel road. The station was relocated upstream of the road in 1998. All data available for the calibration were collected prior to the relocation. The stream crosses under the road at a low point, and runoff from the road enters the stream just above the former location of GS16. Woman Creek hillslopes 16, 19, 20, 21, and 22 were used in the calibration. The habitats represented on these hillslopes are improved road, xeric tall grass prairie, mesic mixed grassland, and short marsh. The top-slope, side-slope, and improved road soils are represented on the hillslopes. Stream flow and meteorological data for the years 1995 to 1998 were used for the calibration.

The short period of record for GS16 meant that few large events were represented in the calibration data set. The May 17, 1995, storm, estimated to have a return period of about 12 to 15 years, provided a very important, relatively high runoff event that was captured in the monitoring data. Figure A-32 plots observed and WEPP-estimated runoff versus rainfall for the years 1995 through 1998. The maximum runoff and stream flow point represents the May 17, 1995, event. Only two events delivered more than 30 mm (1.2 in) of rain. The calibrated WEPP model predicted these two events very well. The WEPP estimates for these two events are slightly higher than the observed data, but overall the WEPP estimates are within the catter of the obsrved data and the shape of the response curve is similar. The most scatter occurs in the region of very low flow coinciding with the area of largest uncertainty due to the method of calculation of observed stream flow by the subtraction of estimated baseflow.

Figure A-32 plots observed and estimated sediment yields, versus measured stream-flow (minus baseflow) and estimated runoff. The log- log plot enables examination of the lower portion of the correlation where all of the observed data reside. At the lower flow events, the WEPP-predicted sediment yield exceeds the observed data, but this is the area of greatest uncertainty and contributes a small percentage of the total sediment yield. The observed data are all for flow events under 1 mm. At flows above 0.1 mm the observed and predicted compare well. Mean sediment yields also compare well. Collection of additional TSS data for higher flow conditions at station GS16 would benefit future improvement and updating of the erosion model.

A.7.3.2 Woman Creek at Gaging Stations GS06 and GS05

The South Woman Creek sub-basin, tributary to gaging station GS06, is mostly west of the RFETS boundary. South Woman Creek headwaters are west of the Site where flood irrigation return-flows from Smart Ditch II provide baseflow to the creek channel. WEPP hillslopes 4 and 5 drain to the off-Site portion of South Woman Creek. Hillslopes 12 and 13 feed the South Woman Creek channel just east of the western Site boundary. Hillslopes 4 and 5 are grazed, mixed mesic grassland areas with relatively gentle slopes, and hillslopes 12 and 13 are steep firebreak roads. The combined runoff from hillslopes 4, 5, 12, and 13, plus baseflow, is measured at GS06.

Flow is measured continuously with a 6-inch Parshall Flume at GS06. Accurate flow record is available for 1995 to present. Samples of total suspended solids are collected from storm water runoff using an automatic sampler at GS06. The record of measured total suspended solids and corresponding flow data was used to evaluate the WEPP model runoff and erosion parameters.

The baseflow in the flow record was subtracted from the total daily runoff to estimate the runoff yield for each event. The data in Figure A-33 shows a general underestimation of runoff. The drainage area contributing to GS06 upstream from the modeled area is thought to account for a major portion of the difference between predicted and observed data. There are currently no data to quantify the upstream contributions. Baseflow was subtracted out but may have been underestimated. Irrigation practices upstream from GS06 may also confound the estimation of baseflow, which in turn affects estimation of the runoff yield.

Figure A-33 also shows the relationship for sediment yields versus runoff or stream yield. It appears that there is an over-estimation of the sediment yields by WEPP by a factor between less than two to about seven. The mean yielsds over the period of observation compare well and are within one standard deviation.

At GS05 WEPP appears to underestimate flows at precipitaion rates below about 20mm (Figure A-34). For more intense events WEPP appears to predict runoff well, although observed data was not been collected during this period for events above 30 mm. There may again be a problem estimating baseflows, as the observed flows do not appear to respond to precipitation to the degree expected. There appears to be two populations in the observed data: a scattered set below the 1-mm runoff level and a group with a well defined trend and higher runoff values. All the observed data are for small events, and the ratio of runoff to precipitation exceeds unity for some events, indicating an overestimation of runoff.

The sediment yield plot (Figure A-34) shows some mixing of the two scattered groups of data, and as with GS06, WEPP appears to overestimate sediment yields; however, most of the data are for extremely low flow events (less than 1-mm runoff yield). The over-estimation for the single observed event with runoff greater than 10 mm is about a factor of five.

A.7.3.3 South Interceptor Ditch (SID)

WEPP results of runoff and sediment yield were compared to Site monitoring data for the SID. The period of comparison was 1995 through 1998 for Site data. Before direct comparisons could be made, data collected at SW027 were adjusted in several ways to allow for a more meaningful comparison with WEPP output. The following discussion describes these data adjustments and presents the results of comparison of WEPP output for runoff and sediment yield with the SID data.

A.7.3.3.1 Runoff Comparison

WEPP was not designed to estimate runoff from large impervious areas. A majority of the flow of the SID is due to runoff originated from large impervious areas in the IA. Therefore, runoff from the portions of the SW027 drainage located in the IA was subtracted from the SW027 runoff totals. Data from gauges monitoring industrial area runoff to the SID (GS21, GS22, GS24, and GS25) were summed and compared to SW027 discharge to develop a relationship between precipitation and IA runoff. A minimum estimate of losses of the IA runoff contribution along the SID due to infiltration and trapping was also generated. Inclusion of these minimum losses improved the correlation slightly, but had little effect on the numerical relationship between observed flow at SW027 and IA contribution to that flow. The observed linear relationship (R^2=0.88) was then applied to develop an estimate of SW027 flow excluding the IA contribution.

Summing the WEPP output for the SID hillslopes presents a same-day runoff response to precipitation events, whereas SW027 data exhibit a lag time of up to three days between precipitation and outflows. This is the time it takes the runoff to move through the SID. SW027 hydrographs and hyetographs were superimposed for data collected from 1995 through 1998, and the observed durations of rainfall-runoff events were identified and recorded. In some cases, events overlapped, and the hydrograph response from one precipitation event could not be distinguished from that of the next event. In these cases, the events were grouped as a series. Precipitation and runoff were then summed over each event period and WEPP output was summed over the same event periods.

Runoff from snowfall events is not instantaneous. Including snowfall events in the comparison of observed to estimated runoff can lead to misinterpretations of the data. Therefore, 15 of the 44 storm periods identified for SW027 from 1995 through 1998 that occurred as snowfalls were removed from the comparison set, leaving 29 events for the comparison.

WEPP output estimates runoff at the base of each hillslope, as opposed to runoff at the end of the drainage, where SW027 measures surface flow. HEC-6T was used to route the WEPP output to SW027; however, HEC-6T output is not presented in this section. The runoff from all hillslopes was summed for this comparison to assess WEPP results without confounding by additional modeling.

The graphical comparison of WEPP-estimated runoff results and SW027 measured data for 1995 through 1998 is presented in Figure A-35. The data sets compare well, though WEPP output fairly consistently underestimates runoff response as calculated. Particularly good correlation is observed for the May 17 – May 20, 1995 precipitation event. Comparison of the WEPP 100-year rainfall runoff response and the SW027 data (1995 though 1998) is presented in Figure A-36. Again, the data sets compare well, with very similar response for the May 1995 event. This figure suggests that WEPP output tends to under-predict runoff for events smaller than about 20 mm. This may partially explain the apparent under-prediction of runoff seen in Figure A-36. More than one-third of the events in the 100-year simulation correspond to a total precipitation of less than 20 mm, and most of the remaining events (storm periods) include at least one day with a light rain amounting to less than 20 mm. In short, WEPP-predicted rainfall-runoff relationships compare well to Site data, though runoff for small events seems to be consistently under-predicted. This should have a small effect on long term estimates or predictions for intense single events.

A.7.3.3.2 Sediment Yield Comparison

The WEPP-estimated sediment yields also indicate overestimation of erosion. The estimated yield for the May 17, 1995 event appears to be overestimated by a factor of about 20. The SID is a depositional environment with dense stands of tall vegetation (e.g. cattail, trees, etc.). The sum of the sediment yields for every SID watershed hillslope are plotted in Figure A-37. Deposition in the SID channel is not accounted for in this analysis or the analyses for the other gaging stations. An overestimate of the sediment yield by the total summation method used is expected and desired. The sediment transport model results are a better gage of the accuracy of the erosion model (see Appendix C).

A.8 Summary

A model was created and calibrated to predict the measured rain simulator plot data provided by CSU. The simulator plot model produced conservative, but reasonable results when transferred to the longer Site hillslopes. The runoff and erosion estimates were compared directly with observed stream flow and TSS data for Site gaging staions. Overall the WEPP estimates are most accurate for larger events. These are the events that contribute the most to soil loss and control long term average erosion rates. The limitations of the monitoring data discussed in Section A.7.1 highlights the uncertainty created by use of the present surface-water database for calibration of the erosion model or the sediment transport model to Site conditions. Modification of existing surface water monitoring programs are being evaluated to enable data collection that will enhance the models' power for making management decisions.

A.9 References

All references are located in Section 12 of the main report.

APPENDIX A TABLES

Table A-1. RFETS Plant Habitat Types

Habitat Code	Habitat Description
XTGP	Xeric Tall Grass Prairie
NEEDLE	Xeric Needle-and-Threadgrass Prairie
MESIC	Mixed Mesic Grassland
REGRASS	Reclaimed Grassland
AGRASS	Annual Grass and Forb Community
SMARSH	Short Marsh
TMARSH	Tall Marsh
WETMEDW	Wet Meadow
LEAD	Leadplant Riparian Shrubland
SHORTUP	Short Upland Shrubland
RIPWOOD	Riparian Woodland
WILLOW	Riparian Willow Shrubland
GRAZED	Grazed Off-Site Areas
IMPROAD	Improved Gravel Road
MEROAD	Unimproved, Partially Vegetated Road
PAVEMENT	Paved Surfaces (e.g. Buildings, Roads, Parking Lots)

Table A-2. Vegetation Data Documentation for the WEPP model

The following information documents what datasets were used and how values were calculated for initial use in the WEPP model at RFETS. Eleven of the plant community types shown on the 1996 vegetation map, with additional plant community information provided for two of the communities using data collected from the 881 hillside area. The plant community types included: xeric needle and threadgrass prairie, xeric tallgrass prairie, mesic mixed grassland, reclaimed grassland, short marsh, wet meadow, willow riparian shrubland, leadplant riparian shrubland, riparian woodland, short upland shrubland, tall marsh, 881 hillside mesic mixed grassland, and 881 hillside reclaimed grassland. The datasets used for providing the various vegetation measurements were taken from the Baseline Biological Characterization of the Terrestrial and Aquatic Habitats at Rocky Flats Plant (DOE, 1992a), Rocky Flats Environmental Technology Site Ecological Monitoring Program 1995 Annual Report (DOE, 1995c), Site Vegetation Report: Terrestrial Vegetation Survey (1993-1195) for the Rocky Flats Environmental Technology Site (K-H 1997), 1997 Annual Wildlife Survey Report (K-H, 1998b), and 1997 Annual Vegetation Report (K-H, 1998c) documents. The data cited from the OU1 study sites is from in DOE, 1992.

Initial Conditions Files

Parameters in the initial conditions files used in the management files of the model were as follows:

1. Initial frost depth (m), real-(frdp)

Estimated from the site weather data.

2. Average rainfall during growing season (m), real-(pptg)

Estimated from the site weather data.

3. Initial residue mass above the ground (kg/m2), real-(rmagt)

For each of the plant communities the initial plant residue was assumed to be 50% of the annual biomass production. It was assumed that by midwinter that approximately 50% of the previous years biomass production would have decomposed. Where more multiple site data were used, values were averaged. In some cases no RFETS data were available for some plant communities, so the most similar RFETS plant community data were substituted. Data used for each of the plant communities follows:

xeric needle and threadgrass prairie – Used EcMP site TR06 biomass data from 1994 (DOE 1995; K-H 1997).
Xeric tallgrass prairie – Used EcMP site TR01 and TR12 biomass data from 1994 (DOE 1995; K-H 1997).
Mesic mixed grassland – Used EcMP site TR02, TR04, and TR11 biomass data from 1994 (DOE 1995; K-H 1997).
Reclaimed grassland – Used EcMP site TR07, TR08, and TR09 biomass data from 1994 (DOE 1995; K-H 1997).
Annual grass/forb – Used EcMP site TR02 biomass data from 1994 (DOE 1995; K-H 1997).
Short marsh – Used 1991 OU1 biomass data from sites MA01R and MA02R (DOE 1992).
Wet meadow – No wet meadow biomass data were available, however, due to its similarity to the mesic mixed grassland, biomass data from EcMP sites, TR02, TR04, and TR11 in 1994 were used (DOE 1995; K-H 1997).
Willow riparian shrubland – No biomass data were available from this community, however, due to its similarity to the riparian woodland, biomass data from OU1 sites, MW02A and MW03A from 1991 were used (DOE 1992).
Leadplant riparian shrubland – No biomass data were available for this community, however, due to its understory similarity to the mesic mixed grassland, biomass data from EcMP sites, TR02, TR04, and TR11 in 1994 were used (DOE 1995; K-H 1997).
Riparian woodland – Biomass data from OU1 sites, MW02A and MW03A from 1991 were used (DOE 1992).
Short upland shrubland – No biomass data were available from this community, however, due to its similarity to the riparian woodland, biomass data from OU1 sites, MW02A and MW03A from 1991 were used (DOE 1992).
Tall marsh –Biomass data from OU1 sites MA03A and MA04A were used (DOE 1992).

881 Hillside mesic mixed grassland – Biomass data from the 881 Hillside grassland site MG03A was used.
881 hillside reclaimed grassland – Biomass data from the 881 hillside reclaimed grassland site MG03A and the 1994 EcMP reclaimed grassland sites, TR07, TR08, and TR09 were used (DOE 1992, 1995; K-H 1997).

4. Initial residue mass on the ground (kg/m2), real-(rmogt)

For each of the plant communities the initial litter residue was assumed to be 50% of the litter present on the ground during the previous season. It was assumed that by midwinter that approximately 50% of the litter would have decomposed.

Xeric needle and threadgrass prairie – Used EcMP site TR06 litter data from 1994 (DOE 1995; K-H 1997).
Xeric tallgrass prairie – Used EcMP site TR01 and TR12 litter data from 1994 (DOE 1995; K-H 1997).
Mesic mixed grassland – Used EcMP site TR02, TR04, and TR11 litter data from 1994 (DOE 1995; K-H 1997).
Reclaimed grassland – Used EcMP site TR07, TR08, and TR09 litter data from 1994 (DOE 1995; K-H 1997).
Annual grass/forb – Used EcMP site TR02 litter data from 1994 (DOE 1995; K-H 1997).
Short marsh – No litter data was collected in this community, so the 1991 OU1 biomass data from sites MA01R and MA02R was used (DOE 1992). Values were averaged from both sites and then doubled to provide an estimate of the litter amount. This was done because in general, litter amounts were approximately twice that of the biomass values at those sites where it was measured.
Wet meadow – No wet meadow litter data were available, however, due to its similarity to the mesic mixed grassland, litter data from EcMP sites, TR02, TR04, and TR11 in 1994 were used (DOE 1995; K-H 1997).
Willow riparian shrubland – No litter data were available from this community, however, due to its similarity to the riparian woodland, biomass data from OU1 sites, MW02A and MW03A from 1991 (DOE 1992) were used and doubled as mentioned above for the short marsh community
leadplant riparian shrubland – No litter data were available for this community, however, due to its understory similarity to the mesic mixed grassland, litter data from EcMP sites, TR02, TR04, and TR11 in 1994 were used (DOE 1995; K-H 1997).
Riparian woodland – Because no litter data were available from this community, biomass data from OU1 sites, MW02A and MW03A from 1991 were used (DOE 1992) and doubled as mentioned above for the short marsh community.
Short upland shrubland – No litter data were available from this community, however, due to its similarity to the riparian woodland, biomass data from OU1 sites, MW02A and MW03A from 1991 (DOE 1992) were used and doubled as mentioned above for the short marsh community.
Tall marsh – No litter data were available from this community, however, biomass data from OU1 sites MA03A and MA04A were used (DOE 1992) and doubled as mentioned above for the short marsh community.
881 hillside mesic mixed grassland – No litter data were available from this community, however, biomass data from the 881 hillside grassland site MG03A was used (DOE 1992) and doubled as mentioned above for the short marsh community.
881 hillside reclaimed grassland – No litter data were available from this community, however biomass data from the 881 hillside grassland site MG03A and the 1994 EcMP reclaimed grassland sites, TR07, TR08, and TR09 were used (DOE 1992, 1995; K-H 1997) and doubled as mentioned above for the short marsh community.

5. Initial random roughness for rangeland (m), real-(rrough)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

6. Initial snow depth (m), real-(snodpy)

An initial snow depth of zero was assumed.

7. Initial depth of thaw (m), real-(thdp)

Estimated from the site weather data.

8. Depth of secondary tillage layer (m), real –(tillay(1))

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

9. Depth of primary tillage layer (m), real-(tillay(2))
Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

10. Interrill litter surface cover (0-1), real-(resi); 11) interrill rock surface cover (0-1), real-(roki); 12)interrill basal surface cover (0-1), real(basi); 13) interrill cryptogramic surface cover (0-1), real-(cryi); 14) rill litter surface cover (0-1), real(resr); 15) rill rock surface cover (0-1), real(rokr); 16) rill basal surface cover (0-1), real-(basr); and 17) rill cryptogamic surface cover (0-1), real-(cryr)

For parameters 10–17 the cover data were gathered using a point-intercept cover methodology. None of these data were gathered in such a fashion as to permit separation of rill vs. interrill differences in cover. Therefore the same values were originally assumed for both sets of parameters. No cryptogramic cover was gathered at any of these sites and in reality is rarely present in significant amounts in the plant communities at RFETS.
Xeric needle and threadgrass prairie – Used EcMP site TR06 cover data from 1994 (DOE 1995; K-H 1997).
Xeric tallgrass prairie – Used EcMP site TR01 and TR12 cover data from 1994 (DOE 1995; K-H 1997).
Mesic mixed grassland – Used EcMP site TR02, TR04, and TR11 cover data from 1994 (DOE 1995; K-H 1997).
Reclaimed grassland – Used EcMP site TR07, TR08, and TR09 cover data from 1994 (DOE 1995; K-H 1997).
Annual grass/forb – Used 1994 881 hillside reclamation monitoring cover data (DOE 1995).
Short marsh – Used 1994 EcMP data from transects TR03 T5, TR05 T5, and TR10 T4 (DOE 1995; K-H 1997).
Wet meadow – Used 1994 EcMP site, TR02, TR04, and TR11 cover data because no cover data was available in this community (DOE 1995; K-H 1997).
Willow riparian shrubland – Used 1994 EcMP cover data from transects TR03 T3, TR05 T2, and TR10 T1 (DOE 1995; K-H 1997).
Leadplant riparian shrubland – Used 1994 EcMP cover data from transects TR03 T2 and TR10 T3 (DOE 1995; K-H 1997).
Riparian woodland – Used 1994 EcMP cover data from transects TR03 T1 and TR10 T2 (DOE 1995; K-H 1997).
Short upland shrubland – No cover data was available from this community, however, due to its similarity to the riparian woodland, 1994 EcMP cover data from transects TR03 T1 and TR10 T2 were used (DOE 1995; K-H 1997).
Tall marsh – Cover data from 1991 OU1 sites MA03A and MA04A were used (DOE 1992).
881 Hillside mesic mixed grassland – Cover data from the OU1 881 Hillside mesic grassland site MG03A was used (DOE 1992).
881 Hillside reclaimed grassland – Cover data from the OU1 881 Hillside reclaimed grassland site MG04A was used (DOE 1992).

18. Total foliar (canopy) cover (0-1), real (cancov)

The foliar cover values for the xeric needle and threadgrass prairie, xeric tallgrass prairie, mesic mixed grassland, reclaimed grassland, short marsh, and wet meadow communities came from the same datasets used for parameters 10 – 17. The foliar cover values for the annual grass/forb community came from the 1994 881 Hillside reclamation monitoring cover data (DOE 1995). The foliar cover values for the willow riparian shrubland, leadplant riparian shrubland, riparian woodland, and short upland shrubland communities also used the same datasets listed for parameters 7.1 – 7.8, but the cover amount for the canopy layer (herbaceous, shrub, or tree) with the highest value were used. No total foliar cover data was available for the tall marsh community, so it was estimated using professional judgement. No foliar cover values were available for the 881 hillside mesic mixed grassland and 881 hillside reclaimed grassland communities and so the 1994 EcMP site values for the mesic mixed grassland were used (DOE 1995; K-H 1997).

Plant Management Files

Parameters in the plant management files were as follows:

1. Change in surface residue mass coefficient, real – (aca)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

2. Coefficient for leaf area index, real-(aleaf)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

3. Change in root mass coefficient, real-(ar)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

4. Parameter value for canopy height equation, real-(bbb)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

5. Daily removal of surface residue by insects, real-(bugs)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

6. Frac. of 1st peak of growing season, real-(cf1) and7) 7. Frac. of 2nd peak of growing season, real-(cf2)

The fraction of the vegetation which matured during the 1st and 2nd peaks of the growing seasons (6 and 7) were determined by calculating what percentage of the annual biomass production came from cool season and warm season graminoids. The percentage of total annual biomass production from cool season graminoids was used as the value for the 1st peak (6) and the percentage from warm season graminoids was used as the value for the 2nd peak (7). The datasets used for calculating the percentage of annual biomass production from cool season and warm season graminoids were:

xeric needle and threadgrass prairie – Used EcMP site TR06 biomass data from 1994 (DOE 1995; K-H 1997).
Xeric tallgrass prairie – Used EcMP site TR01 and TR12 biomass data from 1994 (DOE 1995; K-H 1997).
Mesic mixed grassland – Used EcMP site TR02, TR04, and TR11 biomass data from 1994 (DOE 1995; K-H 1997).
Reclaimed grassland – Used EcMP site TR07, TR08, and TR09 biomass data from 1994 (DOE 1995; K-H 1997).
Annual grass/forb – Used EcMP site TR02, TR04, and TR11 biomass data from 1994 (DOE 1995; K-H 1997).
Short marsh – Used 1991 OU1 biomass data from sites MA01R and MA02R (DOE 1992). Considered a unimodal peak because of domination by the rush, *Juncus balticus*.
Wet meadow – No wet meadow biomass data were available, however, due to its similarity to the mesic mixed grassland, biomass data from EcMP sites, TR02, TR04, and TR11 in 1994 were used (DOE 1995; K-H 1997).
Willow riparian shrubland – No biomass data were available from this community, however, due to its similarity to the riparian woodland, biomass data from OU1 sites, MW02A and MW03A from 1991 were used (DOE 1992).
Leadplant riparian shrubland – No biomass data were available for this community, however, due to its understory similarity to the mesic mixed grassland, biomass data from EcMP sites, TR02, TR04, and TR11 in 1994 were used (DOE 1995; K-H 1997).
Riparian woodland – Biomass data from OU1 sites, MW02A and MW03A from 1991 were used (DOE 1992).
Short upland shrubland – No biomass data were available for this community, however, due to its understory similarity to the mesic mixed grassland, biomass data from EcMP sites, TR02, TR04, and TR11 in 1994 were used (DOE 1995; K-H 1997).
Tall marsh – Because the tall marsh is completely dominated by cattails it was considered a unimodal community.
881 hillside mesic mixed grassland – Biomass data from the 881 Hillside grassland site MG03A was used.

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881 hillside reclaimed grassland – Biomass data from the 881 hillside reclaimed grassland site MG03A and the 1994 EcMP reclaimed grassland sites, TR07, TR08, and TR09 were used (DOE 1992, 1995; K-H 1997).

8. C/N ratio of residue and roots, real-(cn)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

9. Standing biomass where canopy cover is 100%,(kg/m2)real-(cold)

In order to calculate the standing biomass where the canopy cover equaled 100%, the first step was to calculate what percent increase in the total foliar cover was necessary to increase the canopy cover to 100%. Total foliar cover values for each community were taken from the datasets used for the initial conditions files number 18. The factor needed to increase this foliar cover amount to 100% was calculated for each community. Then this factor was multiplied by the total amount of biomass in the community, using the datasets mentioned in number 3 for the initial conditions files.

10. Frost free period, (days)integer-(ffp)

Estimated from the RFETS weather database.

11. Projected plant area coefficient for grasses, real-(gcoeff)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

12. Average canopy diameter for grasses, (m)real-(gdiam)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

13. Average height for grasses (m),real-(ghgt)

For communities where graminoid height had been measured at RFETS during biomass sampling, the average height of the 3 tallest graminoid species was used. This was done for the xeric needle and threadgrass prairie, xeric tallgrass prairie, mesic mixed grassland, reclaimed grassland, annual grass/forb, wet meadow, and leadplant riparian shrubland using the biomass datasets mentioned in initial conditions files number 3. The 881 hillside mesic mixed grassland and 881 hillside reclaimed grassland communities used 1994 EcMP mesic grassland graminoid heights (DOE 1995; K-H 1997). For the other communities no Site data was available, so estimates based on professional judgement were used.

14. Average number of grasses along a 100m belt transect, real-(gpop)

No RFETS data was available for this parameter. Values were extrapolated using point-intercept basal cover data. The point-intercept method used a 0.25" diameter rod dropped at 0.5m lengths along a 50m transect (total 100 hits). Given the 0.25" rod diameter a total of 15753.6 rod diameters are present along the length of a 100m long transect. The average number of graminoid basal vegetation "hits" were calculated for each community. This value represented the percentage of hits on graminoid species to be expected along a transect of 100 hits (= a percentage). The calculated percentage for each community was multiplied by 15753.6 to determine an estimate of the number of graminoid stems to be expected along a 100m transect. The cover data used to calculate the percentage of graminoid hits in each community were the datasets used for number 18 of the initial conditions files.

15. Minimum temperature to initiate growth,(degrees C) real-(gtemp)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

16. Maximum herbaceous plant height (m), real-(hmax)

Estimates were made for each community based on professional judgement.

17. Maximum standing live biomass, (kg/m2)real-(plive)

Used biomass values from datasets used for each community given in number 3 of the initial conditions files.

18. Plant drought tolerance factor, real-(pltol)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

19. Day of peak standing crop, 1st peak, (julian day) integer-(pscday)

Original values used were June 25 = Julian day 176. This is an estimate based on professional judgment. For short marsh a value of 217 (Aug. 5) was used because it was considered a unimodal community. Tall marsh was also a unimodal community but the value of 176 was used based on professional judgement.

20. Minimum amount of live biomass, (kg/m2)real-(rgcmin)

Used an estimated value of 0.01 for all communities. No actual Site data are available for this parameter based on professional judgment.

21. Root biomass in top 10cm, (kg/m2)real-(root10)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

22. Fraction of live and dead roots from maximum at start of year, real-(rootf)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

23. Day on which peak occurs, 2nd growing season (julian day), interger-(scday2)

Used September 4 = Julian day 247. This is an estimate based on professional judgment. A value of zero was used for short marsh and tall marsh communities because of their unimodal peak.

24. Projected plant area coefficient for shrubs, real-(scoeff)

Used 0.07, which was the suggested default in the manual for all communities.

25. Average canopy diameter for shrubs (m), real-(sdiam)

No RFETS data was available for this parameter. Estimates for this parameter for each community were based on professional judgment.

26. Average height of shrubs (m), real- (shgt)

No data on shrub height was available for the grassland communities at RFETS. In the woody communities, habitat characterization height data for shrubs from the 1997 Preble's meadow jumping mouse datasets were used (K-H 1998a).

27. Average number of shrubs along a 100m belt transect, real-(spop)

The number of shrubs along a 100m transect were calculated using the same method and datasets used for plant.loop.rangeland file Section 7.4. Cacti were not considered as shrubs for this parameter.

28. Projected plant area coefficient for trees, real-(tcoeff)

Used 0.07, which was the suggested default in the manual for all communities.

29. Average canopy diameter for trees(m), real-(tdiam)

A value of zero was used for the habitats where no trees occurred. For the habitats that have trees, the default value of 2 as suggested in the manual was used.

30. Minimum temperature to initiate senescence, (degrees C)real-(tempmn)

Input values were estimated from values in the WEPP Technical Documentation (Flanagan et al., 1995).

31. Average height for trees (m), real – (thgt)

A value of zero was used for the habitats where no trees occurred. For the habitats that have trees, tree heights were used based on sampling conducted in Woman Creek during 1997 (K-H 1998b).

32. Average number of trees along a 100m belt transect, real-(tpop)

The number of trees along a 100m transect were calculated using the same method and datasets used for plant.loop.rangeland file Section 7.4. Only those plant communities with trees had this calculated for them. A zero was used for those communities without trees.

33. Fraction of initial standing woody biomass, real-(wood)

A value of zero was used for those communities without trees. No RFETS data are available for this parameter for those communities with trees. An estimate of 70% was used for those communities with trees or high shrub amounts (riparian woodland, riparian willow shrubland, leadplant riparian shrubland, and short upland shrubland). The small amount of shrubs (woody vegetation) in the grassland communities was ignored since the amounts would be so small as to be insignificant.

Table A-5. Description of Soils Used in WEPP Soil Input Files

WEPP Soil File Name	Description
TOP-SLOPE Sandy Loam	Soils at top of landscape profile: Flatirons and Nederland Series.
SIDE-SLOPE Sandy Clay Loam	Soils on sideslope of landscape profile: Denver-Kutch-Midway, Denver, Englewood, Leyden-Primen-Standley, Nunn series.
TOE-SLOPE Clay Loam	Soils around the drainages: Englewood, Haverson, Nunn, Standley-Nunn, Valmont series
PAVEMENT "Clay"	Parameters assumed based on output for runoff and erosion for impervious surfaces. Pavement soil file is used for asphalt, concrete, and buildings.
IMPROVED ROAD Sandy Loam	Parameters assumed based on output for runoff and erosion for improved gravel roads and like disturbed areas.

Table A-6. Descriptive Statistics for of RFETS Surface Soil Data Grouped by Landscape Location and for Improved Road Material

Soil Location	Statistics	Sand %	Silt	Clay %	Hydraulic Conductivity[1] mm/hr	Bulk Density g/cm^2	Organic Matter %	CEC meq/100g
Top-Slope Sandy Loam	No.	59	59	59	28	8	57	57
	Mean	63	18	18	116	1	6	22
	St. dev.	13	7	8	77	0	1	6
	CV[2]	0.2	0.4	0.4	0.7	0.2	0.2	0.3
Side-Slope Sandy Clay Loam	No.	76	75	76	9	22	74	74
	Mean	46	26	27	35	1	6	25
	St. dev.	13	6	10	26	0	2	5
	CV	0.3	0.2	0.4	0.7	0.2	0.3	0.2
Toe-Slope Clay Loam	No.	27	27	27	12	10	22	22
	Mean	44	27	28	31	1	5	25
	St. dev.	17	11	12	19	0	2	7
	CV	0.4	0.4	0.4	0.6	0.2	0.4	0.3

[1] Hydraulic conductivity measured at a tension of 15 cm by a tension infiltrometer (Fedors and Warner, 1993).
[2] CV = Coefficient of Variation = (Standard Deviation/Mean)

Particle-Size Analysis For Improved Road Material							
Sieve Size Diameter or #		% Passing	Weight Retained	Weight Retained	% Weight Retained	% Volume Retained	Grain Size Class
(in)	(mm)		(grams)	(grams)			
3/4"	19.1	100	0				
1/2"	12.7	75	286				
3/8"	9.52	63	141.91	784.61	N/A	65.7%	*Gravel*
#4	4.76	42	236.55				
#8	2.38	32	120.15				
#16	1.19	24	87.54				
#30	0.59	20	42.79				
#50	0.297	15	55.68	269.26	81%	27.9%	*Sand*
#100	0.149	10	39.87				
#200	0.074	6	43.38				
<#200	<0.074	N/A	N/A	63.2322	19%	6.4%	*Clay & Silt*
Analyses provided by:			Assumed bulk g/cm^2 densities of 1.8 g/cm^2 for gravel, 1.4 g/cm^2 for sand and 1.5 g/cm^2 for clay				
Pioneer Sand and Gravel, Inc.							

Table A-7. Soil Input Files for the Site Erosion Model

Parameter	Rain Simulator	Top-Slope[1]	Side-Slope	Toe Slope	Improved Road	Paved Road
No. OFEs	1	1	1	1	1	1
Ke Flag[2]	0	0	0	0	0	0
Soil Type	Simulator	Top-Slope	Side-Slope	Toe-Slope	Imp Road	Paved
Texture	Sandy Clay Loam	Sandy Loam	Sandy Clay Loam	Sandy Clay Loam	Sandy loam	Clay
No. Layers	2	2	2	2	3	1
Albedo	0.2	0.2	0.2	0.2	0.45	0.25
Initial Sat	0.29-0.34	0.29-0.34	0.29-0.34	0.29-0.34	0.7	0.99
Ki	9.84e+08	9.8e+08	9.84e+08	9.84e+08	2600000	1
Kr	0.00006	0.00001	0.00006	0.00006	0.005	1e-07
τ_c	0.5	0.5	0.5	0.5	0.3-0.5	200
Ke	15.3	24-12	15.3-2	15.3-2	1.5	0.08
Layer 1						
Layer Depth	290	145	290	215	220	1200
Sand	46	63	46	44	84	0
Clay	27	18	27	28	10	99
Organic Matter	5.7	6	5.7	4.5	.1	0.1
CEC	25	22.5	25	24.6	5	10
% Rocks	10	60	10	10	67	95
Layer 2						
Layer Depth	1330	1050	1330	875	420	N/A
Sand	37.2	70	37.2	34	43	NA
Clay	37.6	13	37.6	40	27	NA
Organic Matter	6.1	4.5	6.1	1.4	4.9	NA
CEC	26.2	17.1	26.2	24	28.3	N/A
% Rocks	10	55	10	10	10	N/A
Layer 3						
Layer Depth	N/A	N/A	N/A	N/A	1270	N/A
Sand	N/A	N/A	N/A	N/A	20	N/A
Clay	N/A	N/A	N/A	N/A	60	N/A
Organic Matter	N/A	N/A	N/A	N/A	1	N/A
CEC	N/A	N/A	N/A	N/A	26.2	N/A
% Rocks	N/A	N/A	N/A	N/A	10	N/A

[1] The side-slope soil file was also used for modeling the unimproved roads.
[2] The Ke Flag determines if an input Ke (0) or a WEPP calculated Ke (1) is used.
N/A = not applicable, no layer 3 for these soils

Table A-8. Predicted Sensitivity of WEPP Model to Input Parameters[1]

WEPP Model Parameter Description	Erosion Sensitivity of Parameter	Sensitive For Single Event?[2]
Initial random roughness (m)	High	yes
Interrill litter surface cover (0-1)	High	yes
Interrill rock surface cover (0-1)	High	yes
Interrill basal surface cover (0-1)	High	yes
Interrill cryptogramic surface cover (0-1)	High	yes
Rill litter surface cover (0-1)	High	yes
Rill rock surface cover (0-1)	High	yes
Rill basal surface cover (0-1)	High	yes
Rill cryptogramic surface cover (0-1)	High	yes
Total canopy cover (0-1)	High	no
Root biomass in top 10cm, (kg/m2)	High	yes
Fraction of live and dead roots	High	no
Initial residue mass above the ground (kg/m2)	Moderate	no
Initial residue mass on the ground(kg/m2)	Moderate	no
Change in surface residue mass coefficient	Moderate	no
Coefficient for leaf area index	Moderate	no
Change in root mass coefficient	Moderate	no
Daily removal of surface residue by insects	Moderate	no
Fraction of 1st peak of growing season	Moderate	no
Fraction of 2nd peak of growing season	Moderate	no
Carbon:Nitrogen ratio of residue and roots	Moderate	no
Average number of grasses along a 100m belt transect	Moderate	yes
Minimum temperature to initiate growth,(degrees C)	Moderate	no
Maximum standing live biomass	Moderate	no
Plant drought tolerance factor, real-(pltol)	Moderate	no
Day of peak standing crop, 1st peak, (julian day)	Moderate	no
Minimum amount of live biomass, (kg/m2)	Moderate	no
2nd growing season peak (julian day)	Moderate	no
Average number of shrubs along a 100m belt transect	Moderate	no
Minimum temperature to initiate senescence, (degrees C)	Moderate	no
Average number of trees along a 100m belt transect	Moderate	no
Fraction of initial standing woody biomass (%)	Moderate	no
Parameter value for canopy height equation	Slight	no
Projected plant area coefficient for grasses	Slight	no
Average canopy diameter for grasses, (m)	Slight	no
Average height for grasses (m)	Slight	no

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Table A-8. Predicted Sensitivity of WEPP Model to Input Parameters, (Continued)

WEPP Model Parameter Description	Erosion Sensitivity of Parameter	Sensitive For Single Event?[2]
Maximum herbaceous plant height (m)	Slight	no
Projected plant area coefficient for shrubs	Slight	
Average canopy diameter for shrubs (m)	Slight	no
Average height of shrubs (m)	Slight	no
Projected plant area coefficient for trees	Slight	no
Average canopy diameter for trees(m)	Slight	no
Average height for trees (m)	Slight	no
Initial frost depth (m)	None	no
Average rainfall during growing season (m)	None	no
Initial snow depth (m)	None	no
Initial depth of thaw (m)	None	no
Depth of secondary tillage layer (m)	None	no
Depth of primary tillage layer (m)	None	no
Standing biomass where canopy cover is 100%,(kg/m2)	None	no
Frost free period, (days)	None	no

1 Adopted from WEPP Technical Documentation (Flanagan et al., 1995)

2 All parameter sensitivities apply to continuous simulations.

Table A-9. WEPP Model Plant Parameter Sensitivity Analysis

WEPP Rangeland Sensitivity Analysis Using 10 Meter Plot With 9% Slope and Calibrated Parameters for Rainfall Simulation Plot, All But One Variable Held Constant, Using the 100 Year Climate File and a 50-Year simulation.

Parameter Value	10 Meter Plot Runoff	10 Meter Plot Sediment Yield	50 Meter Plot Runoff	50 Meter Plot Sediment Yield	Comments	
	mm	Tonnes/ha	mm	Tonnes/ha		
Maximum standing live biomass, plive (kg/m2)						
0.1	10.62	0.327	7.76	0.259	Increases canopy cover, interrril and rill cover, live biomass, and dead biomass Greater effect on erosion than runoff	
0.125	**9.69**	**0.110**	**7.28**	**0.097**		
0.15	9.59	0.052	7.09	0.048		
0.25	9.66	0.011	6.95	0.019		
0.5	9.08	0.006	6.41	0.014		
Canopy Cover, cancov (fraction)						
0.7	10.04	0.227	7.50	0.184	100 yr ave = 63.9	Erosion more sensitive than runoff
0.785	**9.69**	**0.110**	**7.28**	**0.097**	100 yr ave = 73.0	
0.88	9.83	0.045	7.20	0.044	100 yr ave = 81.5	
Roots in top 10 cm, root10 (kg/m2)						
0.5	9.69	0.110	7.28	0.097	No effect over reasonable range.	
1.02	**9.69**	**0.110**	**7.28**	**0.097**		
1.5	9.69	0.110	7.28	0.097		
2.5	9.69	0.110	7.28	0.097		
Live and dead roots, rootf (fraction)						
0.3	9.69	0.110	7.28	0.097	No effect over reasonable range.	
0.4	9.69	0.110	7.28	0.097		
0.5	9.69	0.110	7.28	0.097		
0.66	**9.69**	**0.110**	**7.28**	**0.097**		
0.7	9.69	0.110	7.28	0.097		
Initial Random Roughness, rrough (cm)						
0.0036	9.77	0.110	7.30	0.097	Measured value used, slight effect at +/-25% of value. Effect becomes significant at higher values.	
0.0046	**9.69**	**0.110**	**7.28**	**0.097**		
0.0056	9.65	0.110	7.26	0.096		
0.0076	9.54	0.107	7.08	0.082		
0.01	9.39	0.102	6.88	0.078		
Interrill litter surface cover, resi (kg/m2)					100 year average[1]	
					interrill cover	rill cover
0.33	10.06	0.365	7.49	0.276	67.3	59.6
0.43	9.87	0.218	7.36	0.176	75.4	54.9
0.53	**9.69**	**0.110**	**7.28**	**0.097**	81.4	50.7
0.63	9.61	0.049	7.08	0.048	85.0	46.9
0.73	9.58	0.031	6.84	0.034	87.2	45.7
					Erosion very sensitive	
					Runoff moderately sensitive	

Table A-9. WEPP Model Plant Parameter Sensitivity Analysis (Continued)

Parameter Value	10 Meter Plot Runoff mm	10 Meter Plot Sediment Yield Tonnes/ha	50 Meter Plot Runoff mm	50 Meter Plot Sediment Yield Tonnes/ha	Comments	
Interrill basal surface cover, basi (fraction)						
0.225	9.78	0.143	7.33	0.117	76.6	55.5
0.325	9.74	0.123	7.30	0.104	79.4	52.7
0.425	**9.69**	**0.110**	**7.28**	**0.097**	81.4	50.7
0.525	9.68	0.101	7.27	0.092	82.9	49.2
0.625	9.68	0.096	7.16	0.082	84.1	48.1
					Slight effect on runoff Moderate effect on erosion	
Rill litter surface cover, resr (fraction)						
0.012325	9.98	0.141	7.40	0.127	95.70	32.30
0.02325	9.82	0.127	7.31	0.113	88.20	42.20
0.3325	**9.69**	**0.110**	**7.28**	**0.097**	81.40	50.70
0.4325	9.63	0.090	7.15	0.069	75.50	57.40
0.5325	9.67	0.108	7.16	0.077	67.20	65.70
					Slight effect on runoff Significant effect on erosion	
Rill basal cover, basr (fraction)						
0.05	9.64	0.076	7.11	0.084	89.6	42.50
0.15	9.66	0.092	7.15	0.081	84.8	47.30
0.25	**9.69**	**0.110**	**7.28**	**0.097**	81.4	50.70
0.35	9.74	0.127	7.30	0.106	78.9	53.20
0.45	9.75	0.141	7.32	0.115	77.0	55.10
					Slight effect on runoff	
					Significant effect on erosion	
Interrill rock surface cover, roki (fraction)						
0.01	**9.69**	**0.110**	**7.28**	**0.097**	81.4	50.7
0.05	9.69	0.083	7.28	0.078	85.4	50.7
0.1	9.69	0.060	7.28	0.061	90.4	50.7
Rill rock cover, rokr (fraction)						
0.01	**9.69**	**0.110**	**7.28**	**0.097**	81.4	50.7
0.05	9.69	0.110	7.28	0.096	81.4	54.7
0.1	9.69	0.110	7.28	0.096	81.4	59.7
					No effect on runoff Errosion more sensitive to roki, than rokr	

1 Interrill and rill cover parameters are interactive. A change in resi, basi, resr, basr results in changes in both total interrill and total rill cover.

Table A-10. WEPP Model Soil Parameter Sensitivity Analysis

WEPP Rangeland Sensitivity AnalysisUsing 10 Meter Plot and Calibrated Parameters for Rainfall Simulation Plot, All But One Variable Held Constant (60 mm Rain Simulator Event, Single Storm Mode).

Interrill Erodibility, Ki (kg*s/m4)					
	10 Meter Plot		50 Meter Plot		
Parameter	Runoff	Sediment Yield	Runoff	Sediment Yield	Comments
Value	mm	Tonnes/ha	mm	Tonnes/ha	
9.84E+04	9.69	0.004	7.28	0.020	Greater effect for 10 m plot; larger percentage of erosion is due to interrill processes on shorter plot.
9.84E+05	9.69	0.004	7.28	0.020	
9.84E+06	9.69	0.005	7.28	0.021	
9.84E+07	9.69	0.014	7.28	0.028	
9.84E+08	**9.69**	**0.110**	**7.28**	**0.097**	
9.84E+09	9.69	0.553	7.28	0.394	
Rill Erodibility, Kr (s/m)					
0.0000006	9.69	0.107	7.28	0.079	Greater effect for 50 m plot; larger percentage of is due to rill processes on longer plot.
0.000006	9.69	0.107	7.28	0.080	
0.00006	**9.69**	**0.110**	**7.28**	**0.097**	
0.0006	9.69	0.137	7.28	0.234	
0.006	9.69	0.351	7.28	0.659	
0.06	9.69	0.793	7.28	0.778	
Critical Shear Stress, τ_c (N/m2)					
0.1	9.69	0.120	7.28	0.106	Most sensitive at values less than 1.
0.5	**9.69**	**0.110**	**7.28**	**0.097**	
1	9.69	0.107	7.28	0.008	
1.5	9.69	0.107	7.28	0.079	
2.5	9.69	0.107	7.28	0.079	
12.5	9.69	0.107	7.28	0.079	
Hydraulic Conductivity, Ke (mm/hr)					
0.3	98.35	0.600	89.94	0.725	Runoff is very sensitive to Ke, runoff depth is less on longer slope. This is an artifact of the algorithm used by WEPP.
1.3	58.42	0.460	49.28	0.467	
3.3	35.11	0.347	28.24	0.325	
6.3	22.11	0.228	17.14	0.211	
12.3	12.36	0.139	9.05	0.121	
15.3	**9.69**	**0.110**	**7.28**	**0.097**	
18.3	8.15	0.092	5.78	0.063	
21.3	6.84	0.078	4.73	0.048	

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Table A-10. WEPP Model Soil Parameter Sensitivity Analysis (Continued)

	10 Meter Plot		50 Meter Plot		
Parameter Value	**Runoff mm**	**Sediment Yield Tonnes/ha**	**Runoff mm**	**Sediment Yield Tonnes/ha**	**Comments**
Soil Saturation, Sat (m/m)					
0.14	9.69	0.107	7.28	0.097	Only effects runoff and thus erosion in single storm mode.
0.34	**9.69**	**0.110**	**7.28**	**0.097**	
0.54	9.69	0.107	7.28	0.097	
0.74	9.69	0.107	7.28	0.097	
0.94	9.69	0.107	7.28	0.097	
0.99	9.69	0.107	7.28	0.097	
%Clay (Sand Constant @ 46%)					
12	7.46	0.087	5.36	0.059	Decreasing clay content at with sand constant has a moderate effect on runoff and erosion. Holding the Ke constant infliuence the estimates.
17	8.30	0.095	6.04	0.068	
22	9.06	0.103	6.74	0.082	
27	**9.69**	**0.110**	**7.28**	**0.097**	
32	10.58	0.162	7.75	0.149	
37	11.58	0.155	8.33	0.151	
42	12.44	0.167	9.03	0.152	
% Sand (Clay Constant @ 27%)					
26	6.83	0.067	5.52	0.050	Greater effect on runoff than erosion. Greater effect than change in clay. This is counter-intuitive and may be related to the constant Ke.
36	8.45	0.123	6.38	0.084	
41	8.86	0.129	6.50	0.087	
46	**9.69**	**0.110**	**7.28**	**0.097**	
51	11.41	0.130	8.26	0.112	
56	13.16	0.145	9.57	0.127	
66	17.54	0.166	12.55	0.140	
% Clay/%Sand Varied Together - Total Held Constant					
26/47	8.52	0.059	7.34	0.055	Slight effect on runoff, moderate on erosion.
36/37	9.32	0.130	7.10	0.094	
46/27	**9.69**	**0.110**	**7.28**	**0.097**	
56/17	10.89	0.127	7.87	0.108	
66/7	10.56	0.110	7.64	0.093	

Table A-11. Effect of Slope Length on Runoff and Erosion All Other Parameters Held Constant.

OFE	Precip	Runoff	Effective Infiltration	Peak Runoff	Effective Duration	Ke	Canopy Height	Canop Cover	Interrill Cover	Rill Cover	Live Biomass	Dead Biomass	Rill Width	Sediment Yield	Sediment Yield Per OFE
	mm	mm	mm/h	mm/h	hour	mm/h	m	%	%	%	Kg/m^2	Kg/m^2	m	T/ac	T/ac
1 OFE10 meters long - Equilibrium Event															
1	97.1	**41.1**	92.5	112.0	0.367	15.3	0.28	78.5	79	59.3	0.077	0.187	0.10	**0.176**	0.176
1 OFE 80 meters long - Equilibrium Event															
1	97.1	**41.1**	92.5	59.2	0.695	15.3	0.28	78.5	79	59.3	0.077	0.187	0.15	**0.257**	0.257
8 OFE 10 meters each (80 meters total) - Equilibrium Event															
1	97.1	**41.1**	92.5	59.2	0.695	15.3	0.28	78.5	79	59.3	0.077	0.187	0.08	0.172	0.172
2	97.1	41.1	92.5	59.2	0.695	15.3	0.28	78.5	79	59.3	0.077	0.187	0.10	0.184	0.195
3	97.1	41.1	92.5	59.2	0.695	15.3	0.28	78.5	79	59.3	0.077	0.187	0.11	0.198	0.228
4	97.1	41.1	92.5	59.2	0.695	15.3	0.28	78.5	79	59.3	0.077	0.187	0.12	0.213	0.257
5	97.1	41.1	92.5	59.2	0.695	15.3	0.28	78.5	79	59.3	0.077	0.187	0.13	0.227	0.283
6	97.1	41.1	92.5	59.2	0.695	15.3	0.28	78.5	79	59.3	0.077	0.187	0.14	0.241	0.309
7	97.1	41.1	92.5	59.2	0.695	15.3	0.28	78.5	79	59.3	0.077	0.187	0.15	0.254	0.332
8	97.1	**41.1**	92.5	59.2	0.695	15.3	0.28	78.5	79	59.3	0.077	0.187	0.15	**0.266**	0.354
1 OFE 40 meters - Equilibrium Event															
1	97.1	**41.1**	92.5	82.0	0.501	15.3	0.28	78.5	79	59.3	0.077	0.187	0.14	**0.212**	0.212
1 OFE 320 meters - Partial Equilibrium Event															
1	97.1	**16.1**	92.5	18.7	0.865	15.3	0.28	78.5	79	59.3	0.077	0.187	0.16	**0.195**	0.195
8 OFE 40 meters Each - Partial Equilibrium Event															
1	97.1	**41.1**	92.5	47.5	0.865	15.3	0.28	78.5	79	59.3	0.077	0.187	0.11	0.206	0.206
2	97.1	41.1	92.5	47.5	0.865	15.3	0.28	78.5	79	59.3	0.077	0.187	0.14	0.260	0.313
3	97.1	28.1	92.5	32.5	0.865	15.3	0.28	78.5	79	59.3	0.077	0.187	0.14	0.277	0.312
4	97.1	25.4	92.5	29.3	0.865	15.3	0.28	78.5	79	59.3	0.077	0.187	0.15	0.285	0.307
5	97.1	22.8	92.5	26.4	0.865	15.3	0.28	78.5	79	59.3	0.077	0.187	0.16	0.292	0.320
6	97.1	20.5	92.5	23.7	0.865	15.3	0.28	78.5	79	59.3	0.077	0.187	0.16	0.297	0.322
7	97.1	18.3	92.5	21.1	0.865	15.3	0.28	78.5	79	59.3	0.077	0.187	0.16	0.299	0.314
8	97.1	**16.1**	92.5	18.7	0.865	15.3	0.28	78.5	79	59.3	0.077	0.187	0.16	**0.299**	0.299
1 OFE 320 meters - Partial Equilibrium Event - Ke Adjusted for Slope Length															
1	97.1	**41.1**	74.233	30.84	1.334	5	0.28	78.5	79	59.25	0.077	0.187	0.188	**0.465**	0.465
8 OFE 40 meters Each - Partial Equilibrium Event - Ke Adjusted for Slope Length															
1	97.1	**41.1**	92.5	31.1	1.323	15.3	0.28	78.5	79	59.3	0.077	0.187	0.10	0.198	0.198
2	97.1	41.1	92.5	31.1	1.323	15.3	0.28	78.5	79	59.3	0.077	0.187	0.12	0.253	0.308
3	97.1	35.2	92.5	26.6	1.323	**2.0**	0.28	78.5	79	59.3	0.077	0.187	0.13	0.291	0.367
4	97.1	37.2	89.2	28.1	1.323	**2.0**	0.28	78.5	79	59.3	0.077	0.187	0.15	0.327	0.436
5	97.1	38.5	83.2	29.1	1.323	**2.0**	0.28	78.5	79	59.3	0.077	0.187	0.16	0.365	0.519
6	97.1	39.4	78.3	29.7	1.323	**2.0**	0.28	78.5	79	59.3	0.077	0.187	0.17	0.403	0.592
7	97.1	39.8	75.4	30.1	1.323	**2.0**	0.28	78.5	79	59.3	0.077	0.187	0.18	0.440	0.658
8	97.1	**40.0**	74.2	30.2	1.323	**2.0**	0.28	78.5	79	59.3	0.077	0.187	0.19	**0.474**	0.717

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Table A-12. Summary of Analysis of Runoff Coefficient as a Function of Slope for Rain Simulation Plot

Slope Percent	WEPP Rain (mm)	WEPP Runoff (mm)	WEPP Runoff Coefficient	Comments	
4	60	20.4	0.340		
4	60	19.7	0.328		
4	60	22.6	0.377		
4	60	19.3	0.322		
4	60	21.4	0.357	Average	0.341
4	60	19.5	0.325	Std. Dev.	0.021
9	60	20.6	0.343		
9	60	20	0.333		
9	60	22.9	0.382		
9	60	19.6	0.327		
9	60	21.7	0.362	Average	0.346
9	60	19.8	0.330	Std. Dev.	0.022
20	60	20.7	0.345		
20	60	20.1	0.335		
20	60	23	0.383		
20	60	19.7	0.328		
20	60	21.8	0.363	Average	0.348
20	60	19.9	0.332	Std. Dev.	0.022

Table A-13. Comparison of WEPP Cover Calibrations for 100-Year Simulation to Site Measured Data

		WEPP 100-YEAR ESTIMATE							MEASURED*	
WEPP Cover Type		Leaf Area	Canopy Height	Canopy Cover	Interrill Cover	Rill Cover	Live Biomass	Dead Biomass	Canopy Cover	Interrill Cover
Habitat Description	STATISTIC	Index	m	%	%	%	Kg/m2	Kg/m3	%	%
AGRASS	MEAN	6.43	0.48	85.68	83.08	53.04	0.135	0.216	86	82
Annual Grass and Forbes	STDEV	4.54	0.02	7.16	7.97	2.98	0.037	0.048		
WETMEDW	MEAN	10.34	0.54	92.16	96.33	52.55	0.075	0.204	91	98.4
Wet Meadow	STDEV	14.83	0.04	6.08	4.17	1.97	0.030	0.041		
LEAD	MEAN	12.17	0.91	76.69	97.26	40.64	0.326	0.953	78	99
Leadplant Riparian Shrubland	STDEV	13.18	0.00	10.10	3.13	1.20	0.099	0.153		
WILLOW	MEAN	180.76	2.81	81.65	98.86	50.78	3.027	4.690	80.3	97.3
Willow Riparian Shrubland	STDEV	22.15	0.00	7.29	1.93	1.20	0.707	0.999		
SMARSH	MEAN	30.83	0.56	90.75	94.56	47.38	0.199	0.672	91.3	94.9
Short Marsh	STDEV	37.91	0.04	7.21	2.53	0.56	0.064	0.105		
TMARSH	MEAN	71.00	1.44	57.07	77.27	47.54	0.616	1.362	55	78.3
Tall Marsh	STDEV	86.58	0.07	11.53	2.85	2.10	0.200	0.269		
RIPWOOD	MEAN	486.95	17.62	77.48	99.39	49.85	6.071	8.281	75	99.5
Riparian Woodland	STDEV	85.65	0.00	7.49	2.15	1.10	1.327	1.723		
XTGP	MEAN	17.47	0.48	84.26	97.97	68.64	0.108	0.327	85.8	98.6
Xeric Tall Grass Prairie	STDEV	20.35	0.02	9.10	6.78	2.09	0.031	0.055		
MESIC	MEAN	5.96	0.49	90.49	88.81	60.17	0.120	0.235	91	98.4
Mesic Mixed Grassland	STDEV	4.55	0.01	6.02	5.19	3.09	0.033	0.049		
REGRASS	MEAN	2.01	0.47	80.27	94.60	61.96	0.092	0.274	80	94.9
Reclaimed Grassland	STDEV	2.94	0.04	12.06	3.27	2.88	0.032	0.068		
NEEDLE	MEAN	2.77	0.49	87.52	98.52	70.02	0.182	0.559	89.4	98.4
Needle-&-Threadgrass Prairie	STDEV	1.63	0.01	6.01	4.97	1.51	0.04	0.07		
SIMCAL	MEAN	2.82	0.43	73.02	88.15	38.14	0.07	0.18	73	72
Rain Simulator Plot	STDEV	4.45	0.05	12.91	8.35	3.34	0.03	0.05		
GRAZED	MEAN	2.67	0.36	57.66	73.71	32.38	0.05	0.13	c.a. 50	c.a. 50
Grazed Grassland	STDEV	4.48	0.12	22.36	17.43	6.95	0.03	0.04	(estimated)	(estimated)
IMPROAD	MEAN	0.00	0.00	0.03	36.01	36.06	0.00	0.00	<1	36
Improved Gravel Road	STDEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(estimated)	(estimated)
MEROAD	MEAN	3.08	0.27	66.64	56.38	43.21	0.07	0.15	c.a. 65	c.a. 50
Unimproved Vegetated Road	STDEV	3.91	0.02	12.04	7.40	4.76	0.03	0.04	(estimated)	(estimated)

*Measured data sources:

1. USDOE, 1995, Rocky Flats Environmental Technology Site Ecological Monitoring Program 1995 Annual Report, Rocky Flats Field Office, Golden, CO
2. PTI, Kaiser-Hill, 1997, Site Vegetation Report, Terrestrial Vegetation Survey (1993-1995) for the Rocky Flats Environmental Technology Site, PTI, Boulder, CO.
3. Written communicaton from Mat Johansen, Los Alamos National Laboratory / Colorado State University, September 1999, Data collected 6/99.

Table A-14. Vegetation Parameters Used for the Single Storm Events

Vegetation Community	Leaf Area Index	Canopy Height	Canopy Cover	Interrill Cover	Rill Cover	Live Biomass	Dead Biomass
		m	%	%	%	kg/m^2	kg/m^2
NEEDLE	2.184	0.49	87	95.49	70.5	0.1	0.25
LEAD	7.2	0.942	76	95.99	40.5	0.075	0.154
MEROAD	2.09	0.3	65	54	46	0.051	0.131
MESIC	4.75	0.489	85	88	58	0.063	0.154
AGRASS	5.32	0.47	85	88.3	54.8	0.087	0.177
IMPROAD	0	0.01	3	36.5	36.5	0	0
RIPWOOD	463.75	17.512	77	97.99	50	0.975	0.228
WETMEDW	4.528	0.538	91	95	51	0.064	0.172
GRAZED	4.75	0.329	58	71	38	0.063	0.154
WILLOW	175	2.894	80	95.89	51.4	0.56	0.172
XTGP	9.727	0.48	84	97	67	0.064	0.169
SMARSH	13.475	0.559	90	92.59	47.9	0.125	0.339

Table A-15. Summary of RFETS Stream Gaging Locations, Flow Measurement Devices, and Periods of Record

Station	Drainage Area (Ha)	Startup Date	End Date	Location Description	Flow Measurement Device Description
GS01	884.8 (includes Pond C-2 drainage area)	3/25/98	current	Woman Cr. Flume East of Indiana	18" Parshall flume
GS01-1	884.8 (includes Pond C-2 drainage area)	3/17/94	3/25/98	Woman Creek Upstream 100' from GS01-0	90-degree V-notch weir 3/17/94; 9" Parshall flume July 1995
GS01-0	788.8	9/16/91	3/17/94	Woman Creek at Indiana Street culvert (a.k.a. SW001)	4'-Corrugated Metal Pipe
GS02	63.8	3/16/94	current	Mower Ditch Upstream 100' from GS02-0	90-degree V-notch weir 3/16/94; 9" Parshall flume July 1995
GS02-0	430.5	9/16/91	3/16/94	Mower Ditch at Indiana Street culvert (a.k.a. SW002)	18" Corrugated Metal Pipe
GS03	734.5 (Includes Pond A-4, B-5, and Landfill Pond drainage areas)	9/2/91	current	Walnut Creek at Indiana Street (Co-located with SW003)	Dual, Parallel Parshall flumes, Primary 6" and Secondary 36"
GS04	606.7	10/17/95	current	Rock Creek Upstream 200' from GS04-0	9" Parshall flume
GS06-0	71.8	9/23/91	7/1/95	South Woman Creek at west Site Boundary (a.k.a. SW006)	CMP to 3/26/93; 9.5" Parshall flume installed 3/26/93
GS06	107.9	7/1/95	current	South Woman Creek Downstream 200' from GS06-0	6" Parshall flume
GS07 / SW029	326.2	5/1/91	9/30/96	Woman Creek at Pond C-1 Principal Outlet	90-degree V-notch / broad crested rectangular compound weir

Table A-15. Summary of RFETS Stream Gaging Locations, Flow Measurement Devices, and Periods of Record (continued)

Station	Drainage Area (Ha)	Startup Date	End Date	Location Description	Flow Measurement Device Description
GS09	74.0	5/12/92	current	South Walnut Creek at Pond B-4 Principal Outlet	Dual 30" headgates to 3/16/94; single 30" sharp-crested rectangular weir w/ 3/16/94 (second gate normally closed)
GS08	105.1	3/23/94	current	Pond B-5 Dam I Outlet on South Walnut Creek	2' Parshall flume
GS10-0		6/29/91	4/1/93	South Walnut Creek Below 995	45-degree V-notch weir
GS11	178.4	5/12/92	current	Pond A-4 Dam Principal Outlet	2' Parshall flume
GS12	149.9	5/13/92	current	Pond A-3 Dam Principal Outlet	30" Parshall flume
GS13	100.8	5/2/91	9/11/91	North Walnut Creek at A-Series Bypass	6" Parshall Flume
GS14	361.3	4/7/93	9/30/95	Woman Creek below Pond C-2	9" Parshall flume
GS15	304.6	4/2/93	5/31/95	Smart Ditch at splitter box	6" Parshall Flume
GS16	42.4	12/28/98	current	Antelope Springs Gulch upstream from firebreak road 150'	6" Parshall flume
GS16-0	42.4	4/8/93	11/30/98	Antelope Springs Gulch at north side of firebreak road crossing	6" Parshall flume w/weir
GS17	303.8	4/9/93	5/20/95	Woman Creek above Pond C-1	9" Parshall flume
GS18	202.6	4/9/93	5/2/95	Woman Creek at Old Landfill	9" Parshall flume
GS21	1.1	4/13/95	9/30/96	Building 664 / 805 Parking Lot discharge to SID	3" Cutthroat flume

Table A-15. Summary of RFETS Stream Gaging Locations, Flow Measurement Devices, and Periods of Record (continued)

Station	Drainage Area (Ha)	Startup Date	End Date	Location Description	Flow Measurement Device Description
GS22	7.0	4/18/95	9/30/96	Building 460 Culvert discharge to SID	2' H-flume
GS23	(pipe outfall)	4/13/95	9/30/96	Building 881 septic lift station overflow to SID	0.75 HS-flume
GS24	2.4	6/9/95	9/30/96	Building 881 runoff to SID	0.5' H-flume
GS25	2.7	4/13/95	9/30/96	Building 881 and inner perimeter road runoff to SID	1' H-flume
GS26		2/2/95	10/8/96	Upper Church Ditch below New Landfill construction site	No flow measurement device, Sampling Only
GS27	0.2	3/9/95	current	Drainage swale from northwest portion of 889 D&D area	2" Cutthroat flume
GS28	1.2	5/9/95	8/26/97	Small drainage ditch northwest of B865	4" Cutthroat flume
GS29		3/27/96	9/30/96	East side of 7th at old oil tanks (tanks now removed)	0.75' H-flume
GS30		3/12/96	9/30/96	SW corner Central & 7th	18" Corrugated Metal Pipe
GS31	96.9	10/1/96	current	Pond C-2 Principal Outlet to Woman Creek	2' Parshall flume
GS32	2.3	1/19/97	current	Building 779 drainage to North Walnut Creek	No flow measurement device, Sampling Only
GS33	99.5	9/16/97	current	No Name Gulch at mouth	9.5" Parshall flume
GS34	431.5	2/5/98	current	Walnut Creek above McKay Bypass confluence	1' Parshall flume
GS35	225.5	9/18/97	current	McKay Bypass at mouth	36" Contracted rectangular thin-plate weir

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Table A-15. Summary of RFETS Stream Gaging Locations, Flow Measurement Devices, and Periods of Record (continued)

Station	Drainage Area (Ha)	Startup Date	End Date	Location Description	Flow Measurement Device Description
GS37	3.4	10/28/97	current	Central Avenue Ditch at 443	9.5" Parshall flume
GS38	16.7	1/28/98	current	Central Avenue Ditch below 8th	9.5" Parshall flume
GS39	3.3	1/15/98	current	903 / 904 Pad drainage to Central Avenue Ditch	1' H-flume
GS40	9.9	¾/98	current	750 Pad Culvert drainage to South Walnut Creek	1' Parshall flume
GS41	5.5	6/10/98	current	Love Gulch at mouth, upstream from GS03	0.5' H-flume
GS42	17.9	6/23/98	current	East Spray Field drainage to SID	3" Parshall flume
SW022	31.0	9/11/91	current	Central Avenue Ditch at Inner Perimeter Road	9.5" Parshall flume installed 2/2/95
SW027	86.7	9/11/91	current	South Interceptor Ditch at mouth	Dual 120-degree V-notch weirs installed 4/6/95
SW083		2/2/95	10/8/96	Upper Church Ditch above New Landfill construction site	No flow measurement device, Sampling Only
SW091	4.4	5/4/98	current	500' downstream from original location	6" Cutthroat flume

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Table A-15. Summary of RFETS Stream Gaging Locations, Flow Measurement Devices, and Periods of Record (continued)

Station	Drainage Area (Ha)	Startup DATE	End Date	Location Description	Flow Measurement Device Description
SW091-0	3.8	9/24/91	4/18/95	Original location, northeast PA drainage above perimeter road	No flow measurement device, Sampling Only
SW091-1	4.4	4/18/95	5/4/98	200' downstream from original location, downstream from road	1' H-flume installed
SW 093	97.9	9/11/91	current	North Walnut creek below Portal 3 and 1A tributaries	36" Parshall flume installed 9/11/91; 36" rectangular thin-plate weir w/out end contractions installed 3/12/94.
SW118	20.4	9/11/91	current	North Walnut Creek above Portal 3 and below 371	Concrete drop structure; 169.5-degree v-notch weir installed in 1994
SW120	5.2	9/25/91	current	Central Avenue Ditch below 886	To be installed
SW134	Unknown (pump direct discharged from gravel pits)	5/4/94	current	Rock Creek headwaters tributary from Jefferson County pits	6" Parshall flume
SW998	85.5	5/19/94	9/30/96	West Diversion Ditch near 130 Area	6" Parshall flume

Table A-16. Upland and Sub-Basin Monitoring Data for GS41 and GS42[1]

Gaging Station	Precipitation (mm)	Date	Sample Time	TSS[2] (mg/L)	Runoff (m^3)	Yield (Kg)	Yield (T/ha)	Runoff Coefficient
GS41	2.29	4/25/99	10:12	16	13.1	0.2093	0.00004	0.009
GS41	2.29	4/25/99	11:33	16				
GS41	11.43	4/29/99	9:59	27	37.1	1.5594	0.0003	0.005
GS41	11.43	4/29/99	-	57				
GS41	18.54	4/30/99	-		173.2	-	-	0.014
GS41	10.16	5/1/99	-		120.4	-	-	0.023
GS41		5/2/99	-	-	34.2	-	-	
GS42	13.72	4/25-4/29		NS	NS	NS	NS	NS
GS42	18.54	4/30/99	-	47	38.9	1.8283	0.0001	0.012
GS42	10.16	5/1/99	-	29	4.2	0.1232	0.00001	0.003

1 Installed in fall 1998.
2 TSS = Total Suspended Solids (e.g. sediment)

Table A-17. Rainfall Simulation Plot Data Used in the Calibration of Site WEPP Model

Vegetation and Soil Cover data used in the calibrating the Erosion Model to the Simulator Data						
Plant Parameters						
Plot	Forbes	Grasses	Shrubs	Standing Dead	No Cover	
	%/100					
2	0.24	0.34	0.07	0.04	0.31	
4	0.23	0.44	0.04	0.06	0.22	
6	0.27	0.40	0.05	0.01	0.27	
Mean	0.25	0.39	0.05	0.04	0.27	
Std. Dev.	0.02	0.05	0.02	0.03	0.05	
Cover Parameters						
	Basal	Non-persistent Litter	Persistent Litter	Rock	Gravel	Bare Soil
	%/100					
2	0.28	0.03	0.3	0	0.020	0.35
4	0.39	0.04	0.3	0.03	0.020	0.21
6	0.29	0.02	0.4	0.01	0.020	0.27
Mean	0.32	0.03	0.33	0.01	0.02	0.28
Std. Dev.	0.06	0.01	0.04	0.02	0.00	0.07

Table A-18. Rainfall Simulation Results Used in the Calibration of the Site WEPP Model

Rainfall Simulator Data Provided by the Radiological Health Sciences Department, Colorado State University, 1999

Plot	Antecedent Moisture	Treatment	Precipitation mm/60min	Runoff mm	Runoff Coefficient (ROC)	Peak Runoff mm/hr	Soil Loss kg	Soil Loss T/ha	Average TSS mg/L
2	natural	dry	62.0	14.32	0.231	26.25	0.300	0.092	644
4	natural	dry	58.8	17.71	0.301	60.15	0.412	0.127	715
6	natural	dry	59.3	19.42	0.328	48.36	0.345	0.106	546
		Mean	**60.0**	**17.15**	**0.287**	**44.92**	**0.352**	**0.108**	**635**
		Std. Dev.	**1.7**	**2.60**	**0.050**	**17.21**	**0.056**	**0.017**	**85**
2	natural	wet	30.4	10.33	0.340	37.00	0.147	0.045	437
4	natural	wet	32.9	15.54	0.472	55.59	0.200	0.061	395
6	natural	wet	36.5	12.48	0.342	40.82	0.160	0.049	394
		Mean	33.3	12.78	0.385	44.47	0.169	0.052	409
		Std. Dev.	3.1	2.62	0.076	9.82	0.028	0.008	25
2	natural	very wet	31.5	16.34	0.519	42.87	0.221	0.068	416
4	natural	very wet	31.6	23.83	0.754	58.91	0.220	0.068	284
6	natural	very wet	33.6	19.75	0.588	47.01	0.189	0.058	294
		Mean	32.2	19.97	0.620	49.60	0.210	0.065	331
		Std. Dev.	1.2	3.75	0.121	8.33	0.018	0.006	73
					WEPP Simulation				
1			60	18.64	0.311		0.381	0.117	629
2			60	18.60	0.310		0.326	0.100	539
3			60	18.83	0.314		0.348	0.107	567
4			60	18.52	0.309		0.271	0.083	450
5			60	19.25	0.321		0.354	0.109	565
6			60	18.60	0.310		0.314	0.097	519
		Mean	**60**	**18.74**	**0.312**		**0.332**	**0.102**	**545**
		Std. Dev.	**0**	**0.27**	**0.005**		**0.038**	**0.012**	**59**

APPENDIX A FIGURES

Figure A-1. Comparison of Estimated Rill Erosion On Top-Slope and Side-Slope Soils As a Function of Slope Length

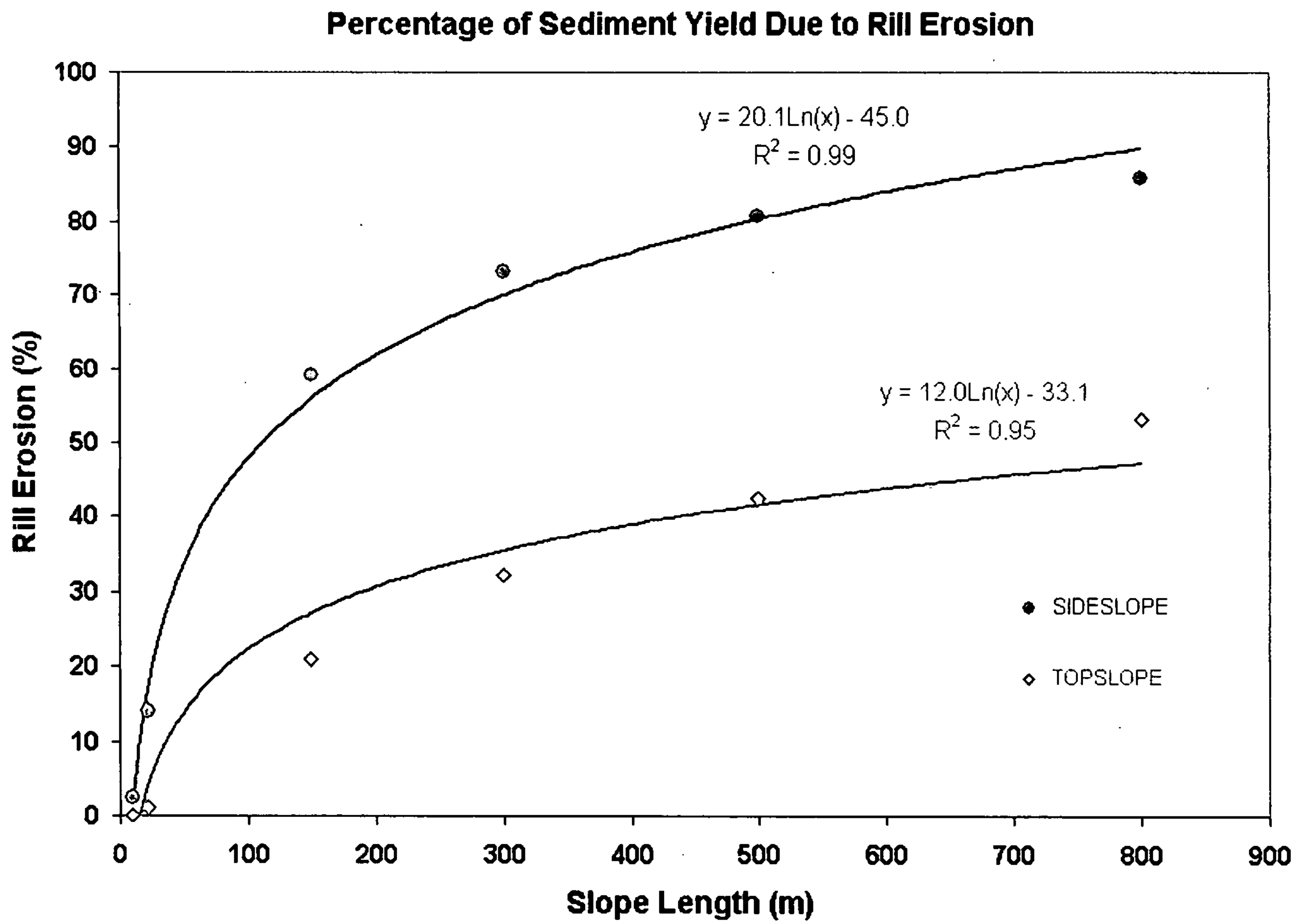
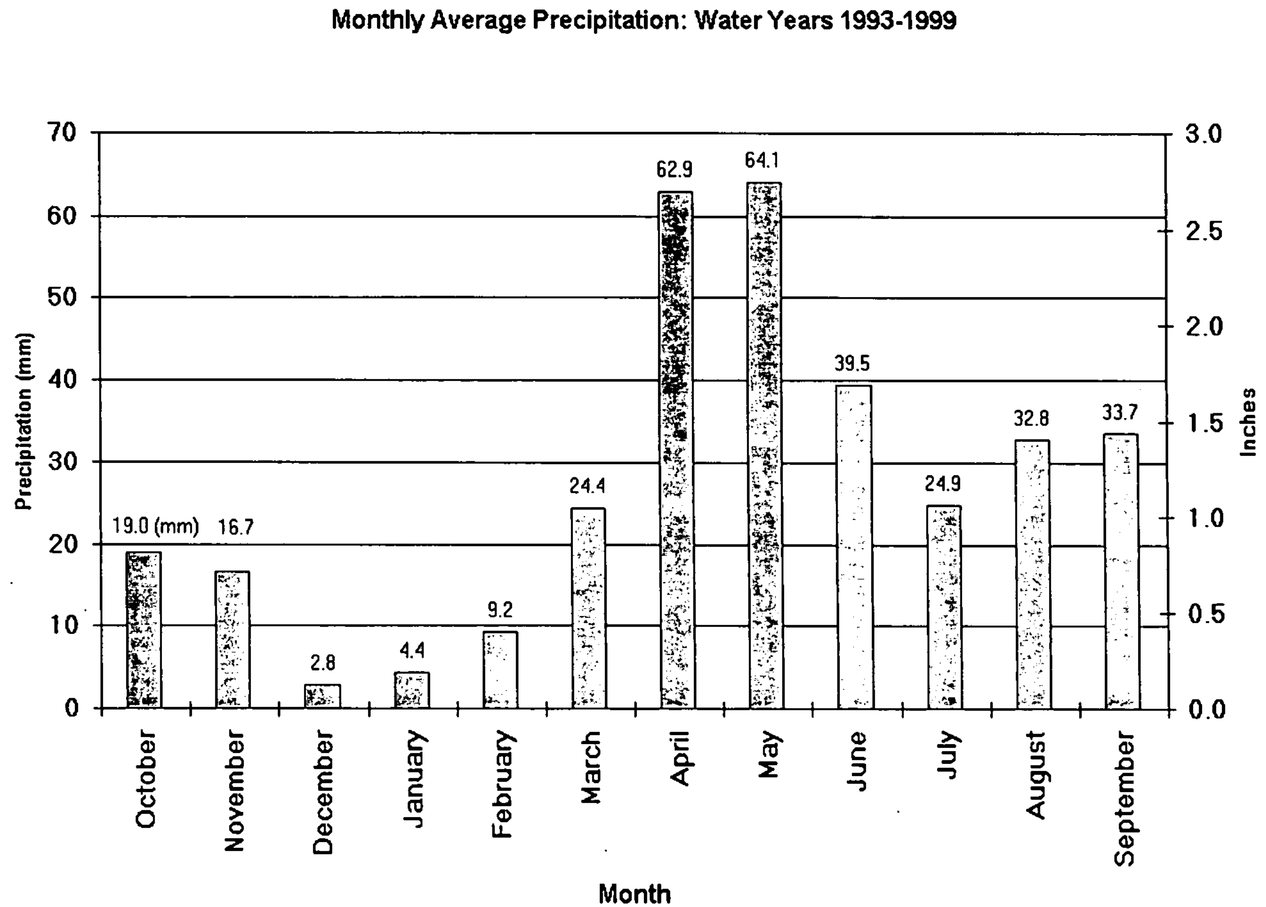


Figure A-2. Daily Precipitation at RFETS, 1995–1998, for 61-Meter Meteorological Tower



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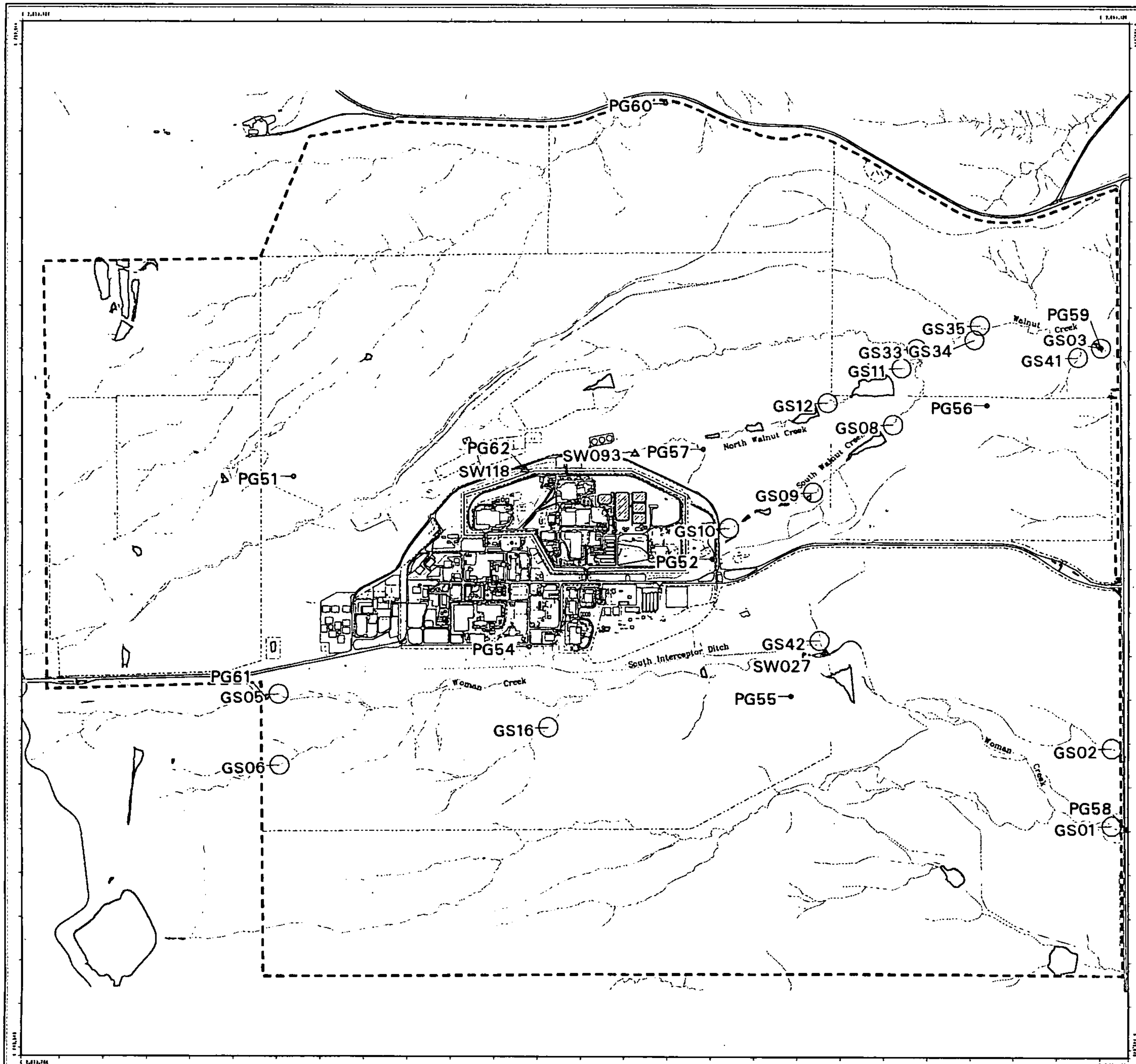

Appendix Figure A-3

Surface Water Monitoring and Gaging Station Locations

EXPLANATION

Monitoring Location

- Gaging Station
- Surface Water Station
- Precipitation Gage Station

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Data Source:
Gaging Stations, Surface Water Stations and Precipitation Gage Stations approved by Steve Singer (RMRS, 303-966-3387).

Scale = 1 : 33530
1 inch represents approximately 2794 feet

500 0 1000 2000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:
KAISER-HILL COMPANY

MAP ID: 2k-0070

August 07, 2000

NT_Svr w:/projects/fy2k/2k-0070/gw_sw_pg.aml

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Figure A-4. Variation of Annual Precipitation, Moving West to East Across RFETS, 1993 - 1998

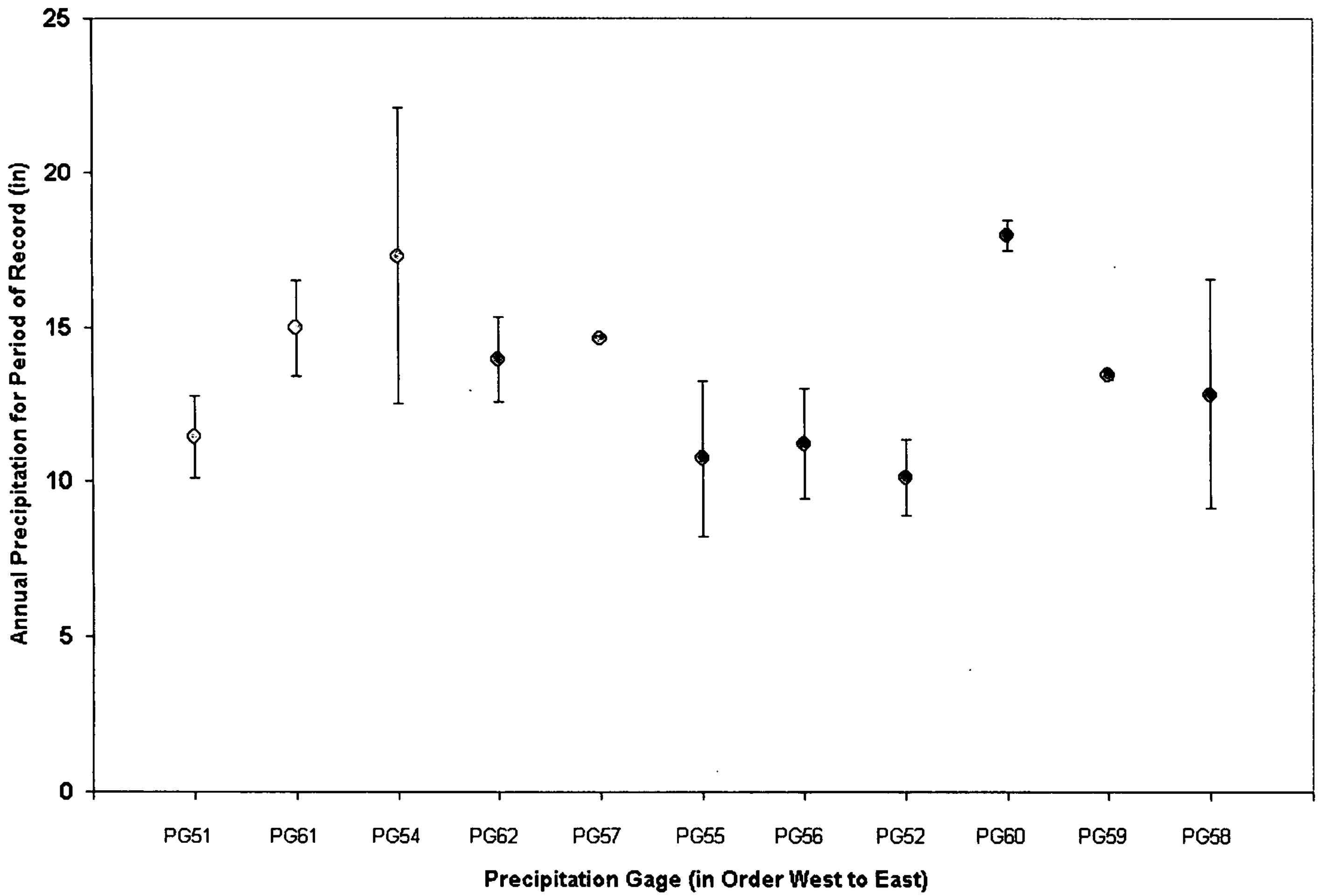

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Figure A-5. Hietograph of Rocky Flats Environmental Technology Site Precipitation 1992-1998

Note: May, 17, 1995 event shown is average of Site gages (64 mm); the value of 74.9 mm used in climate file is from Met. Tower.

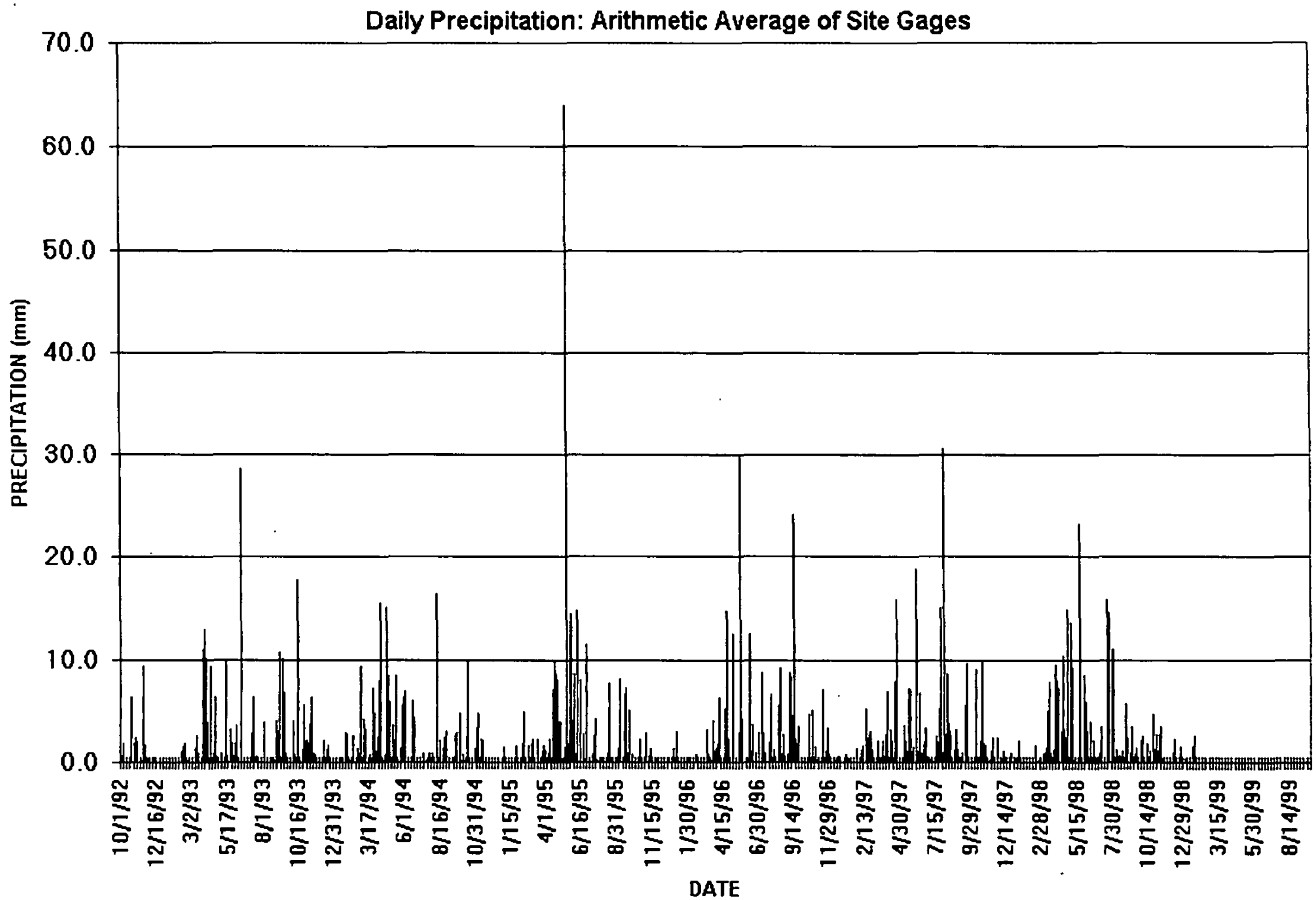

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Figure A-6. Log Pearson Type-III Distribution for Precipitation Depths for Fort Collins, CO CLIGEN Simulation with Rocky Flats Measured Precipitation from 1995 – 1998 Included

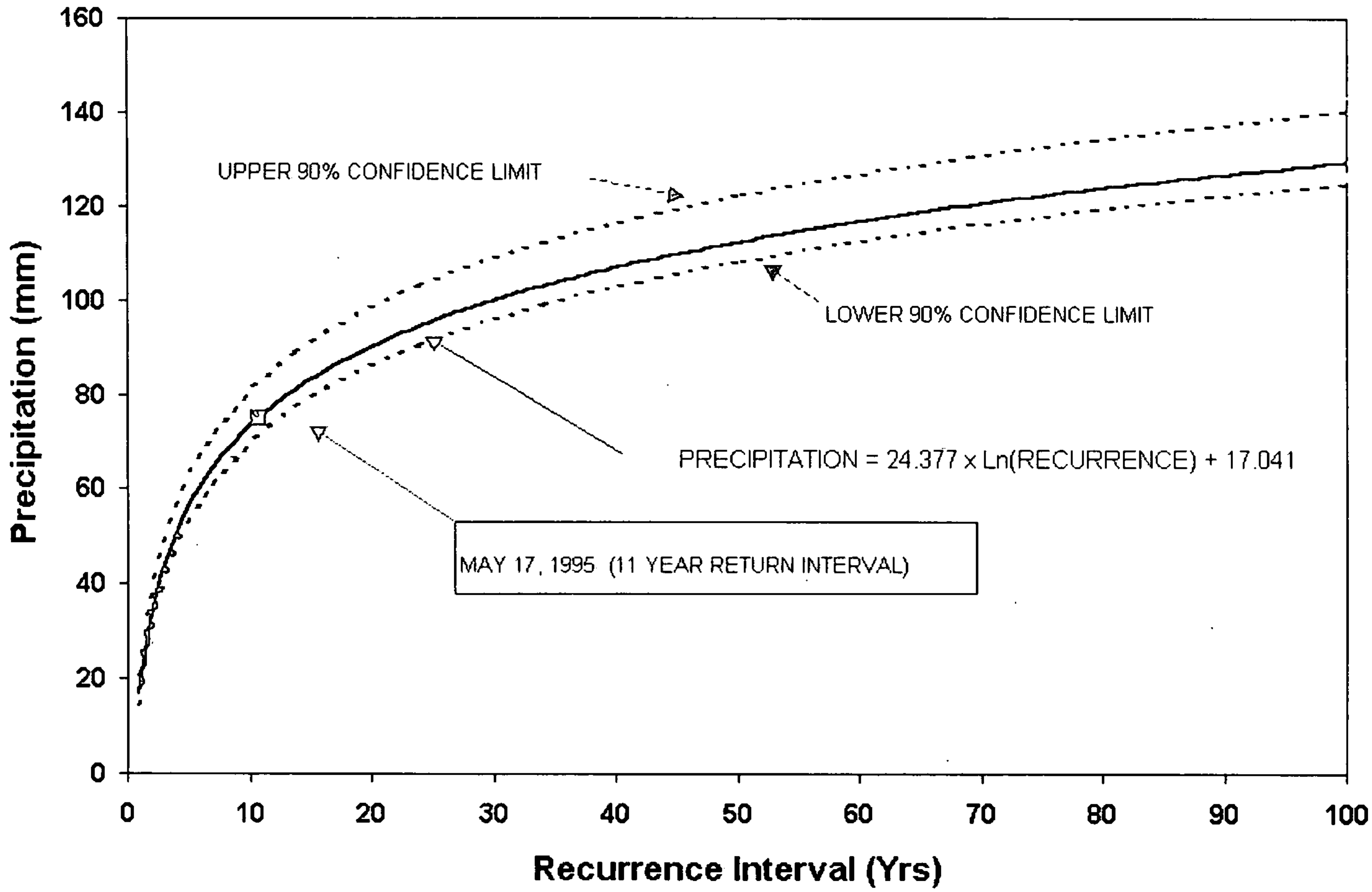

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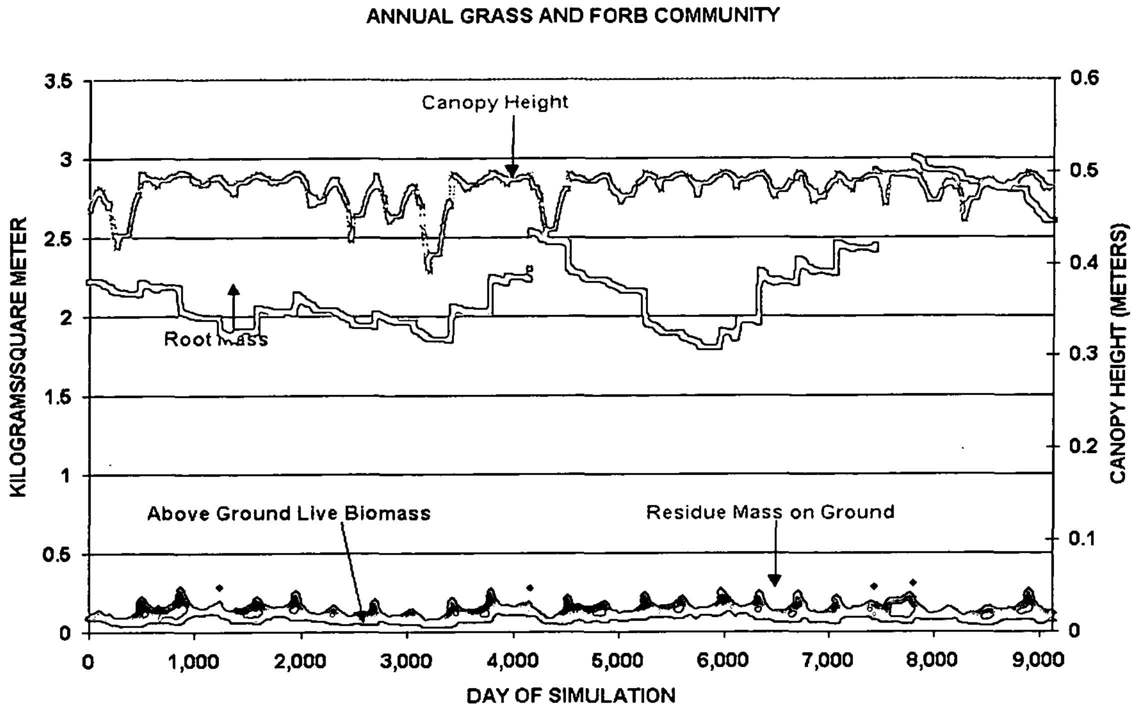
Figure A-7. WEPP-Estimated Plant Growth Patterns for Dominant Habitat Types at RFETS – Annual Grass and Forb Community and Reclaimed Grassland



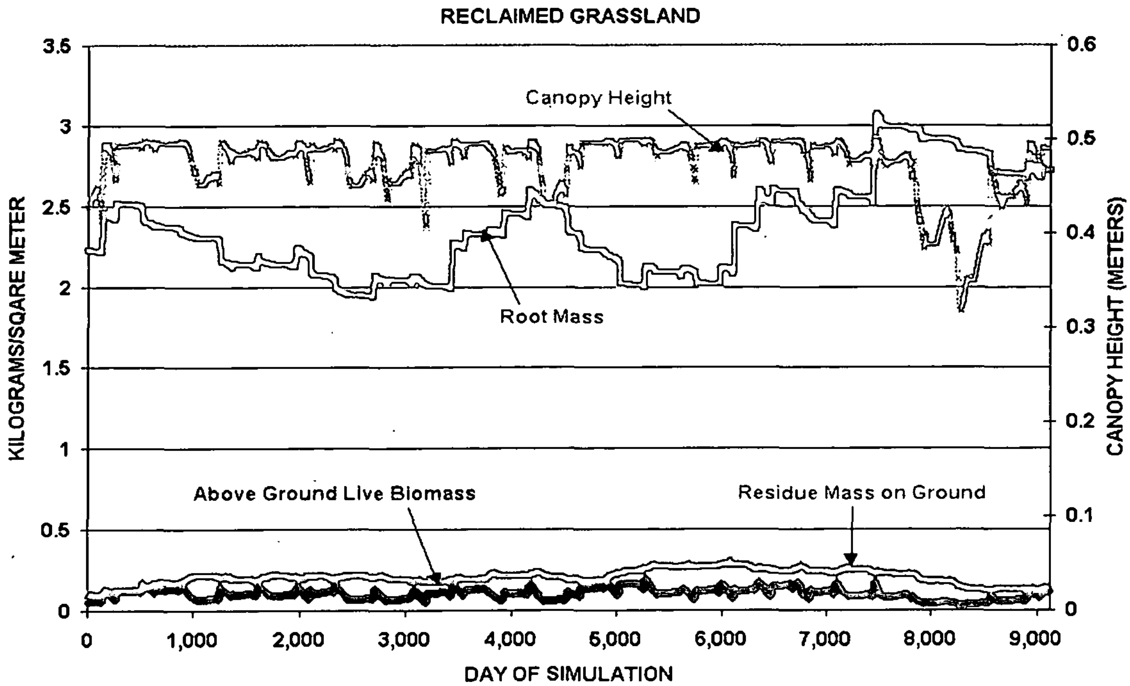


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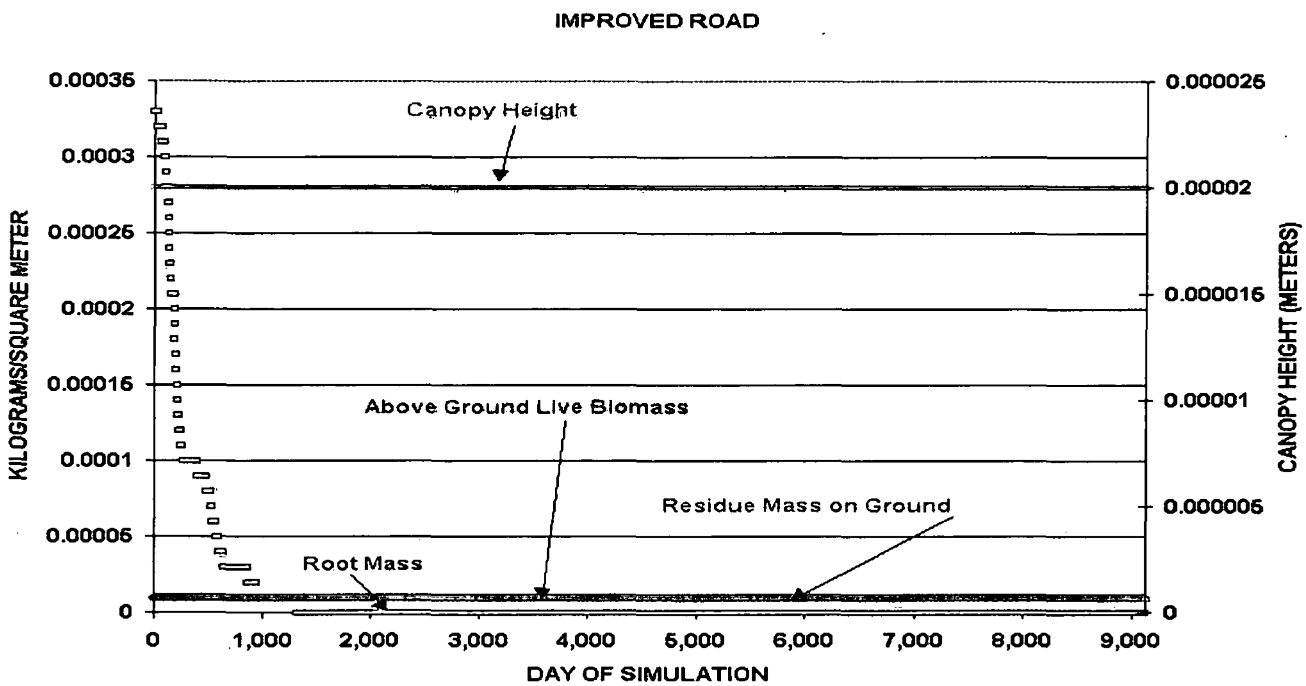
Figure A-8. WEPP-Estimated Plant Growth Patterns for Dominant Habitat Types at RFETS – Improved Roads and Unimproved Roads



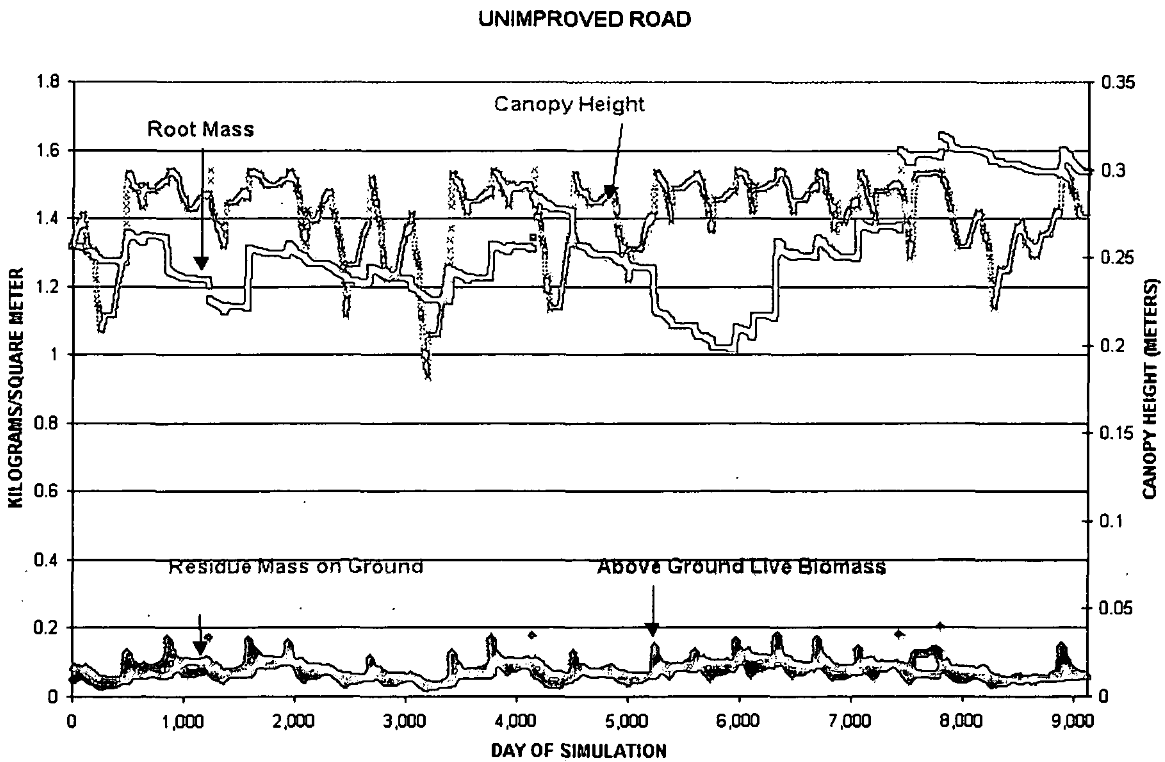


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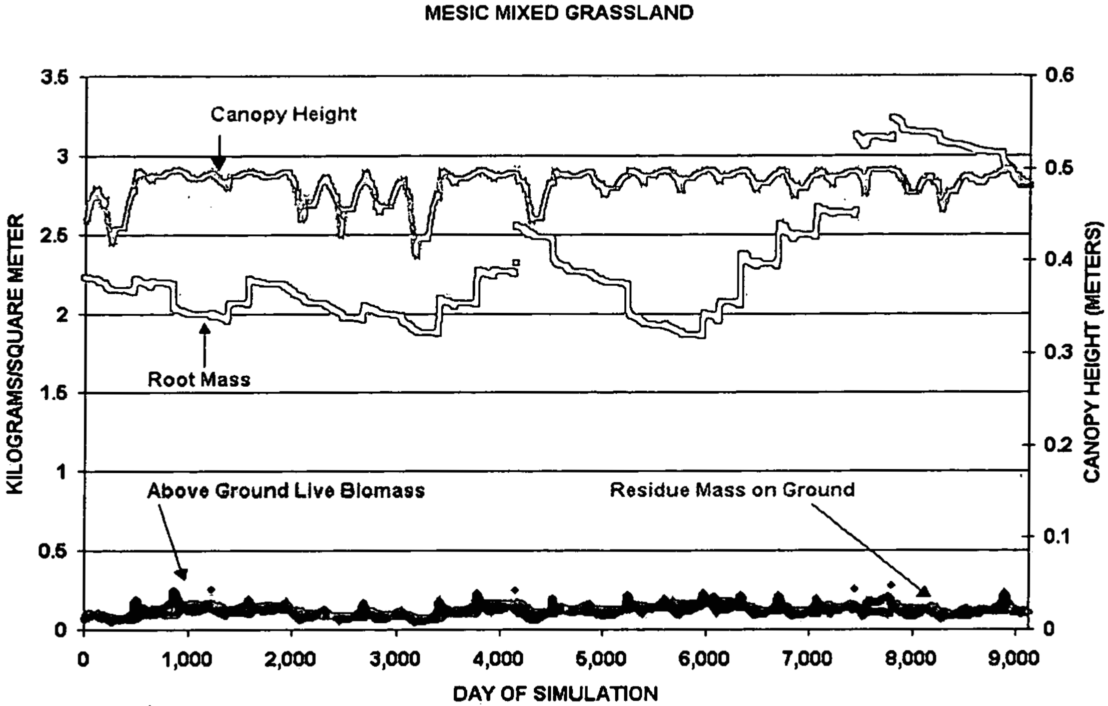
Figure A-9. WEPP-Estimated Plant Growth Patterns for Dominant Habitat Types at RFETS –Grazed Mezic Mixed Grassland and Mezic Mixed Grassland



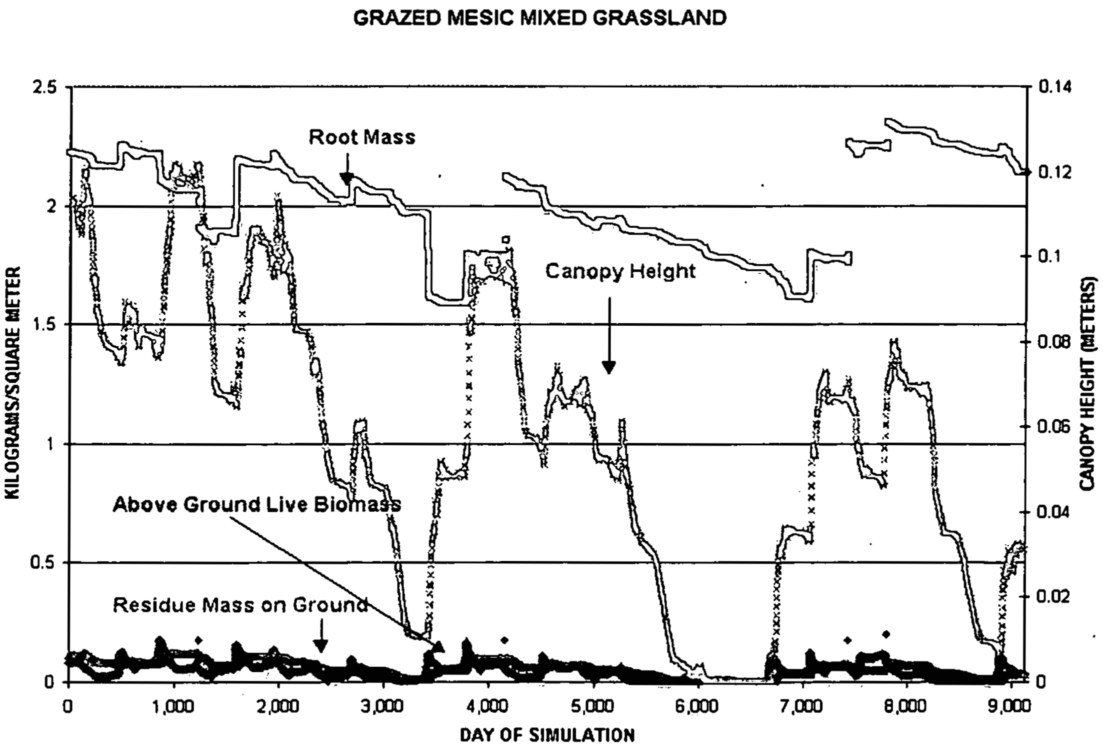


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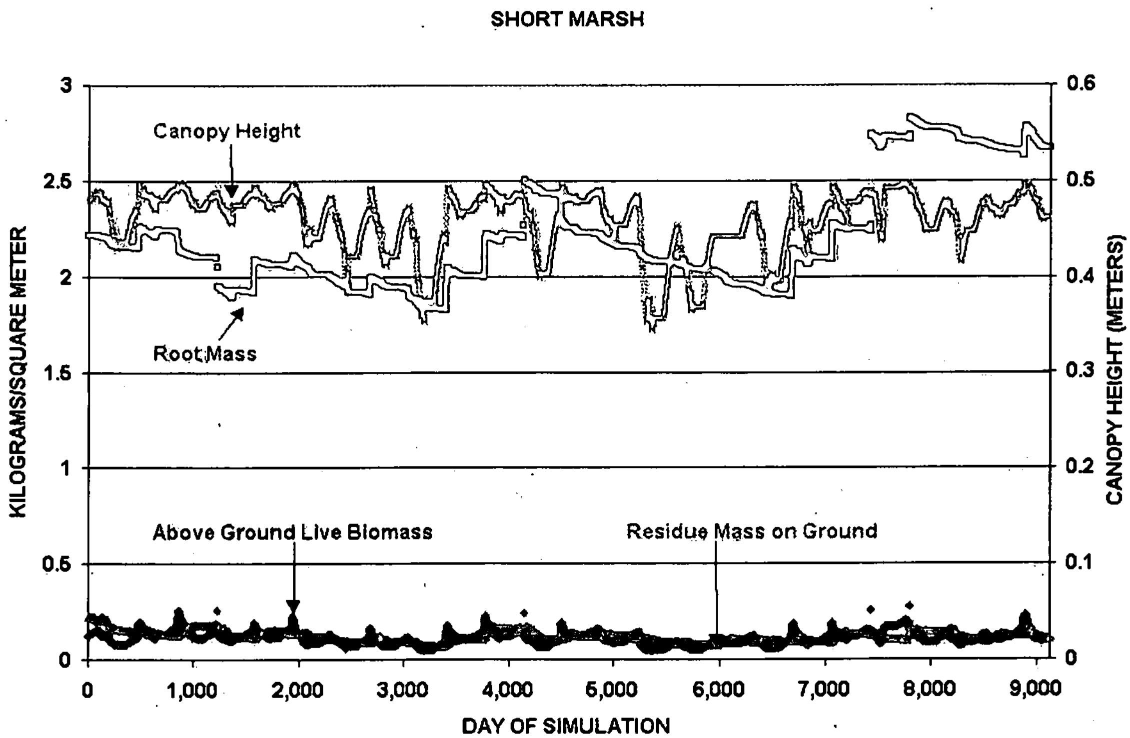
Figure A-10. WEPP-Estimated Plant Growth Patterns for Dominant Habitat Types at RFETS –Tall Marsh and Short Marsh



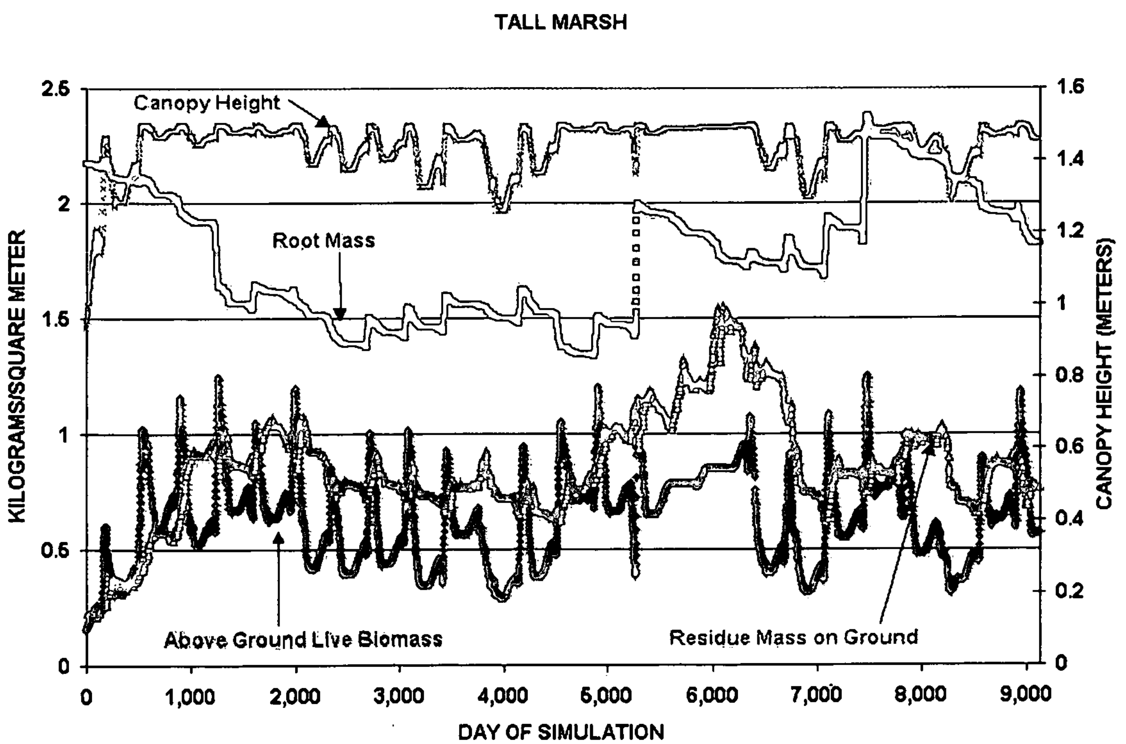


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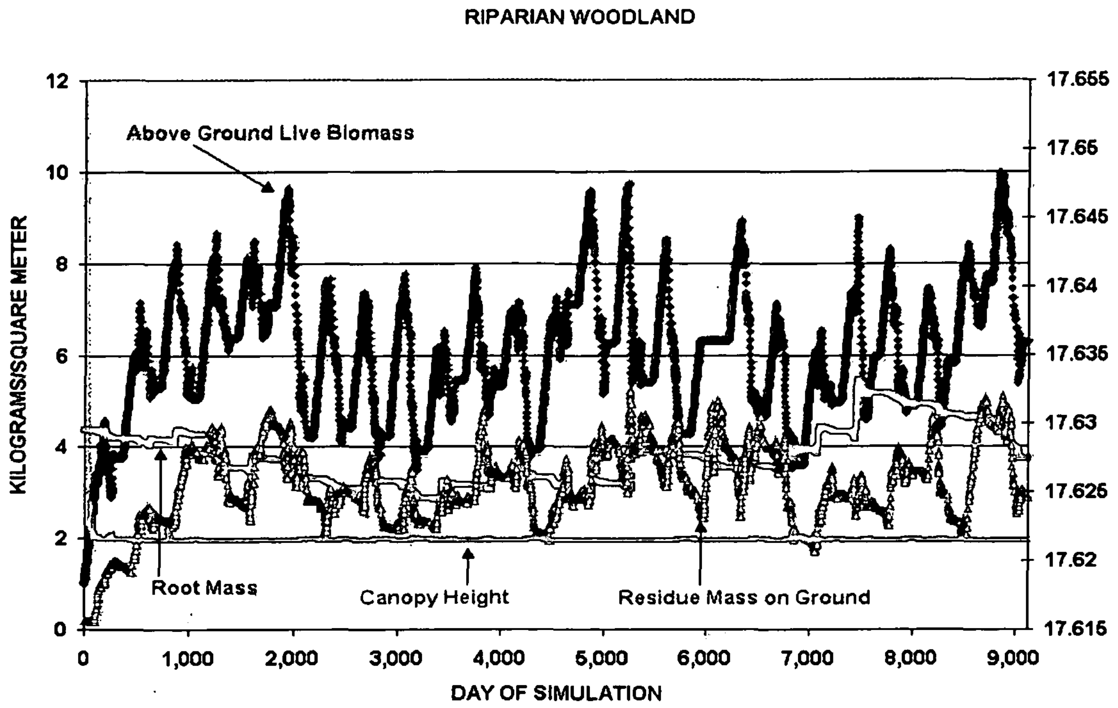
Figure A-11. WEPP-Estimated Plant Growth Patterns for Dominant Habitat Types at RFETS –Riparian Woodland and Wet Meadow



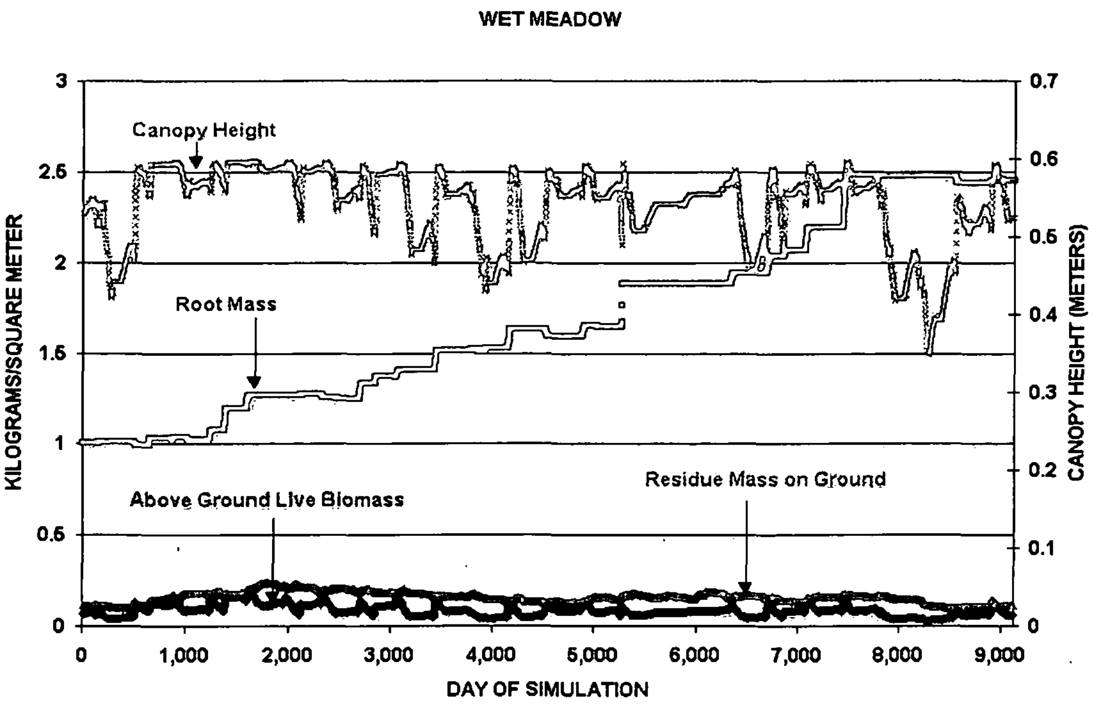


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Figure A-12. WEPP-Estimated Plant Growth Patterns for Dominant Habitat Types at RFETS – Xeric Tall Prairie Grass

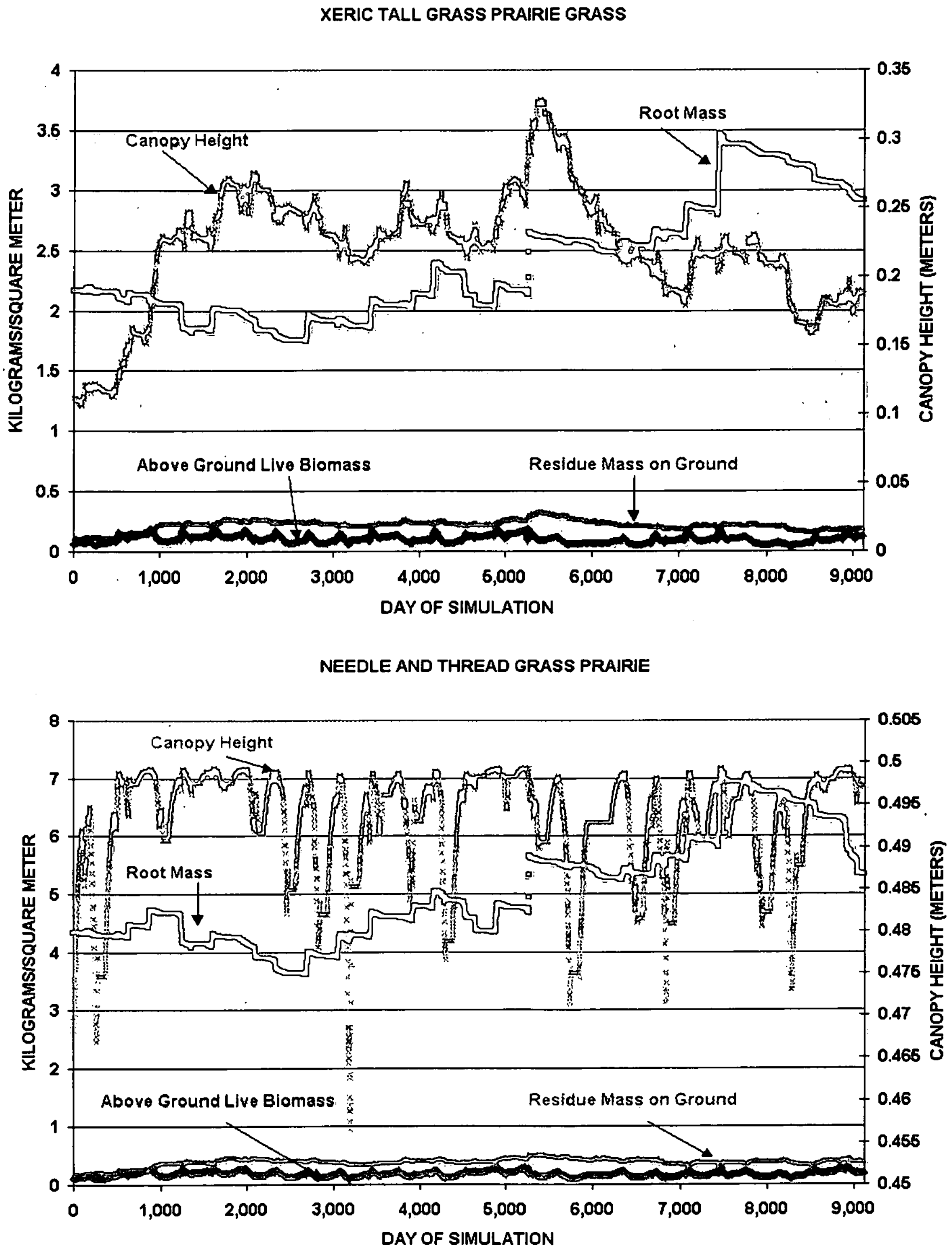

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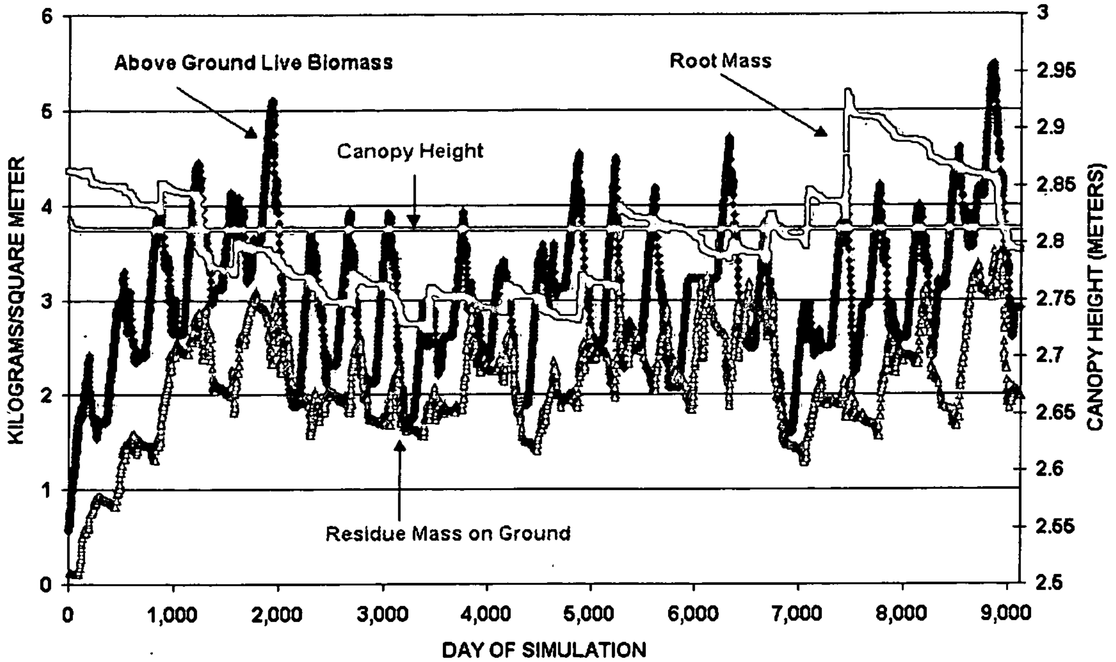
Figure A-13. WEPP-Estimated Plant Growth Patterns for Dominant Habitats at RFETS – Willow Riparian Shrubland and Leadplant Riparian Shrubland

WILLOW RIPARIAN SHRUBLAND



LEADPLANT RIPARIAN SHRUBLAND

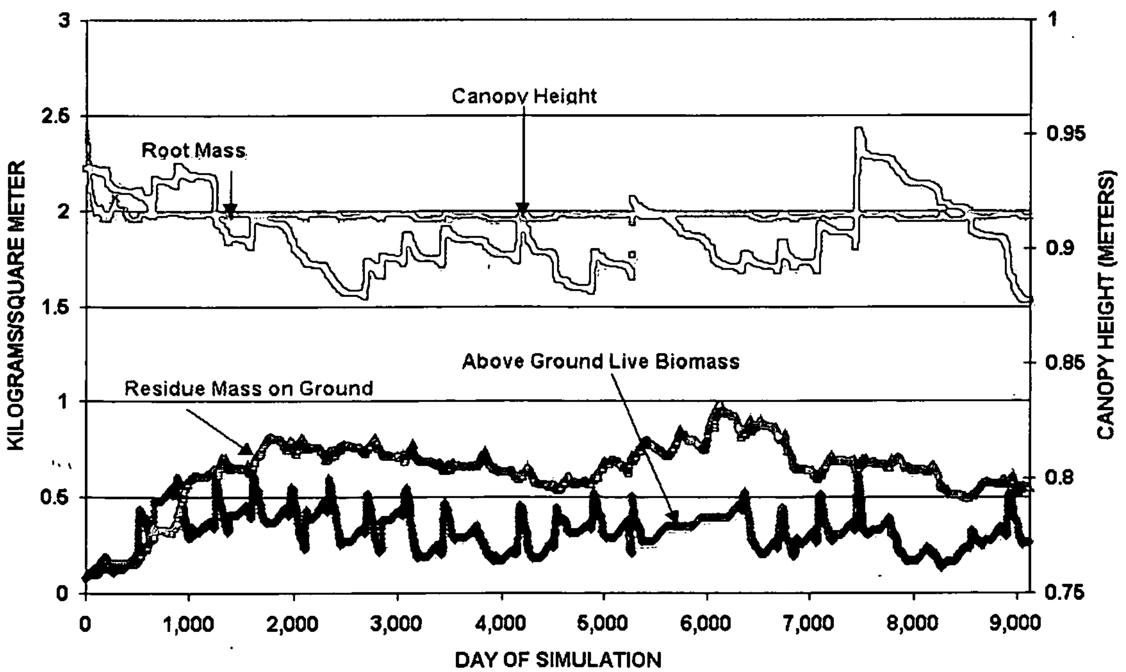


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Figure A-14. Comparison of TSS Data and Average Flow for GS01

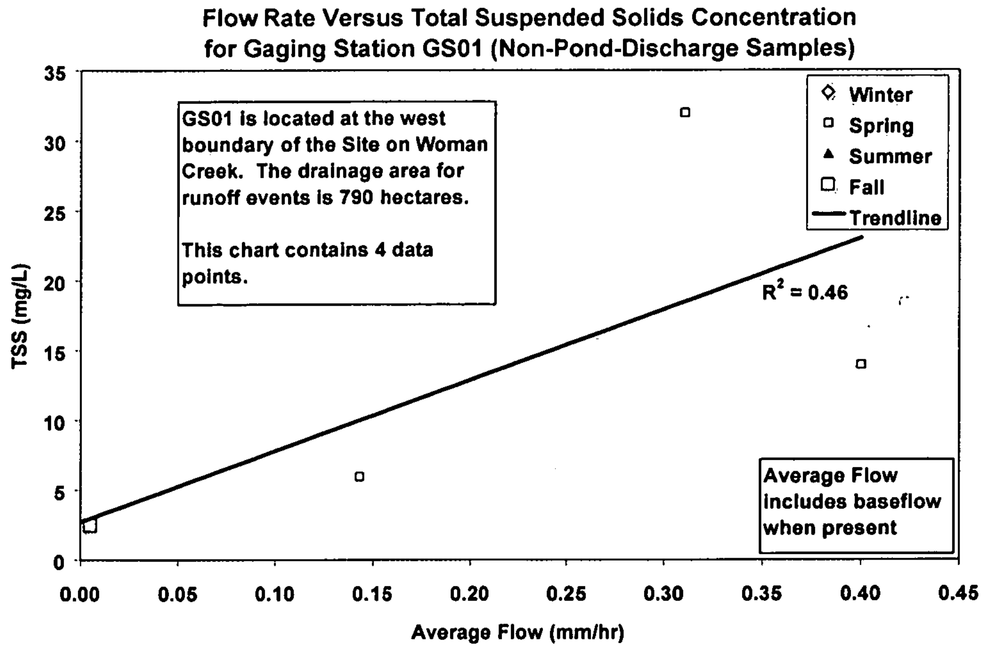

Figure A-15. Comparison of TSS Data and Average Flow for GS03

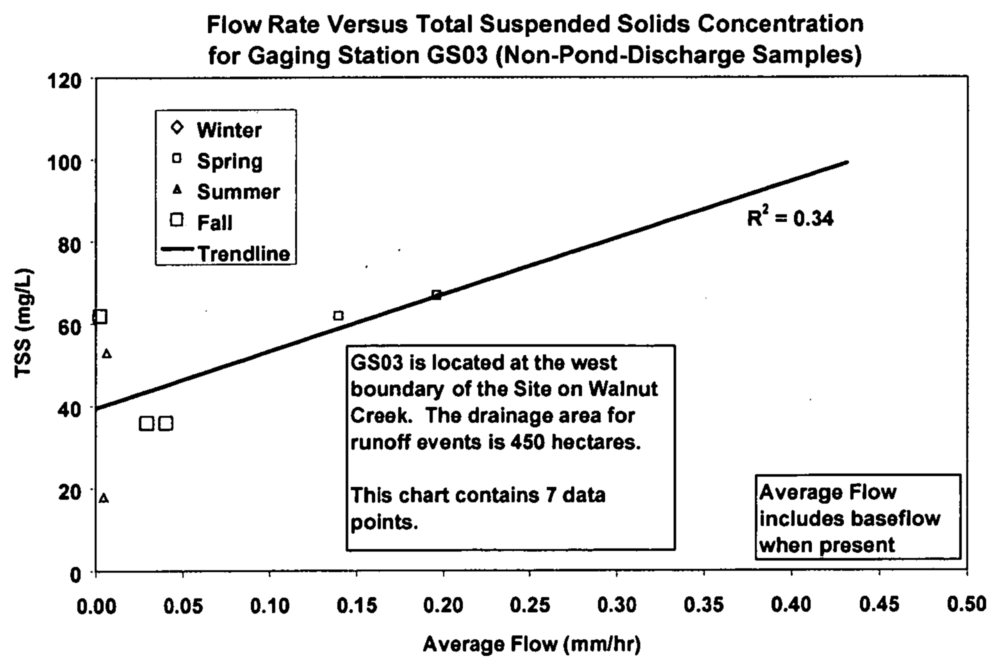

Figure A-16. Comparison of TSS Data and Average Flow for GS07

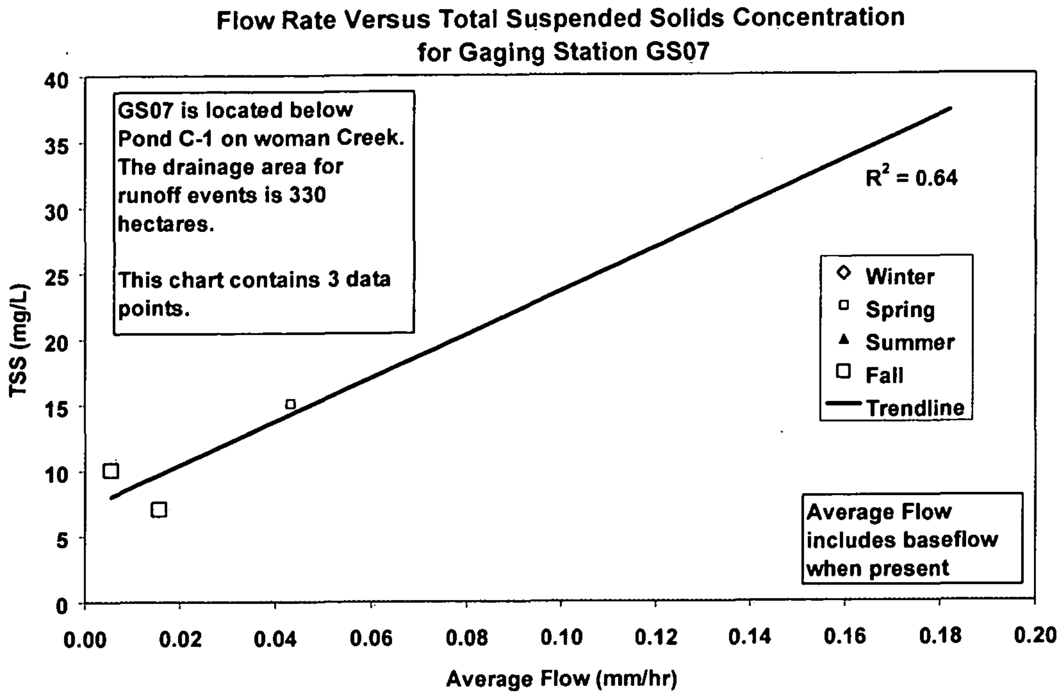

Figure A-17. Comparison of TSS Data and Average Flow for GS08

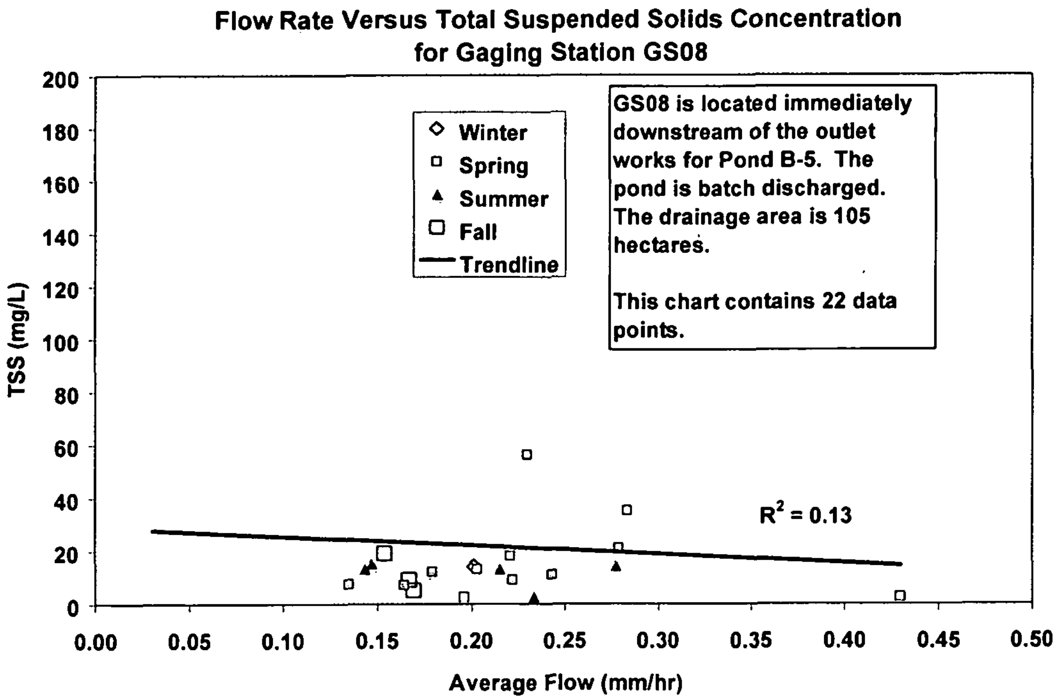

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Figure A-18. Comparison of TSS Data and Average Flow for GS10

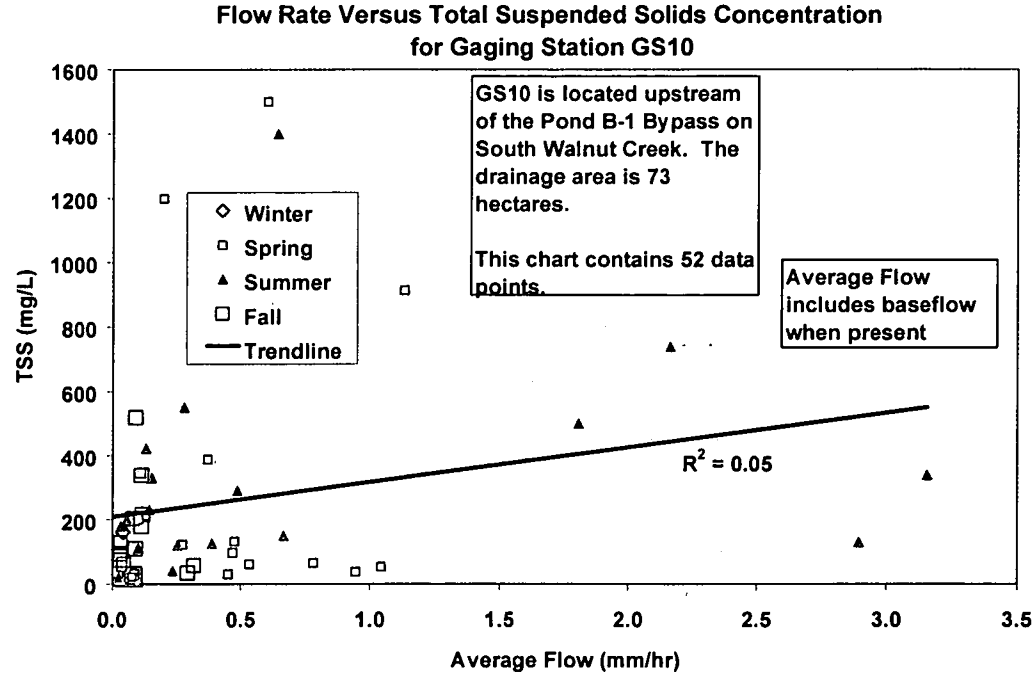

Figure A-19. Comparison of TSS Data and Average Flow for GS14

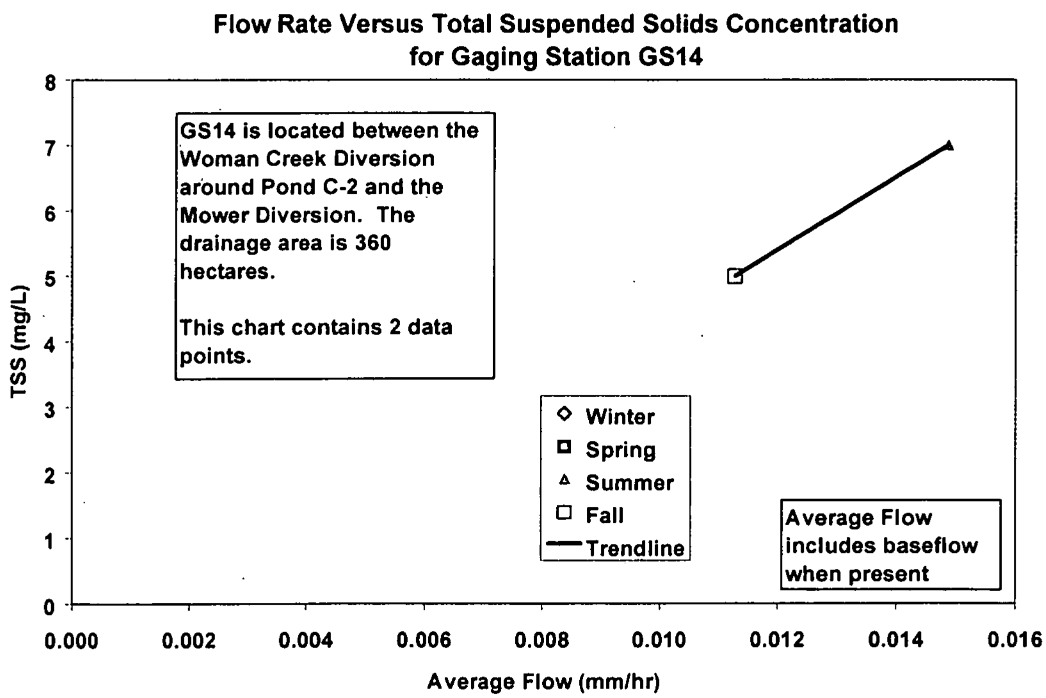

Figure A-20. Comparison of TSS Data and Average Flow for GS16

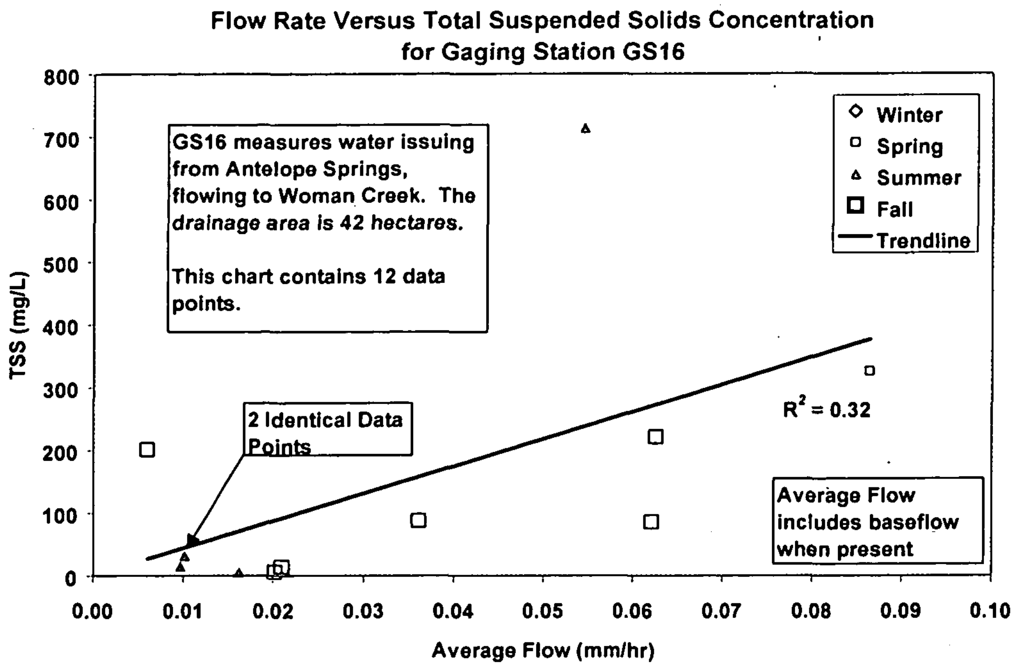

Figure A-21. Comparison of TSS Data and Average Flow for GS17

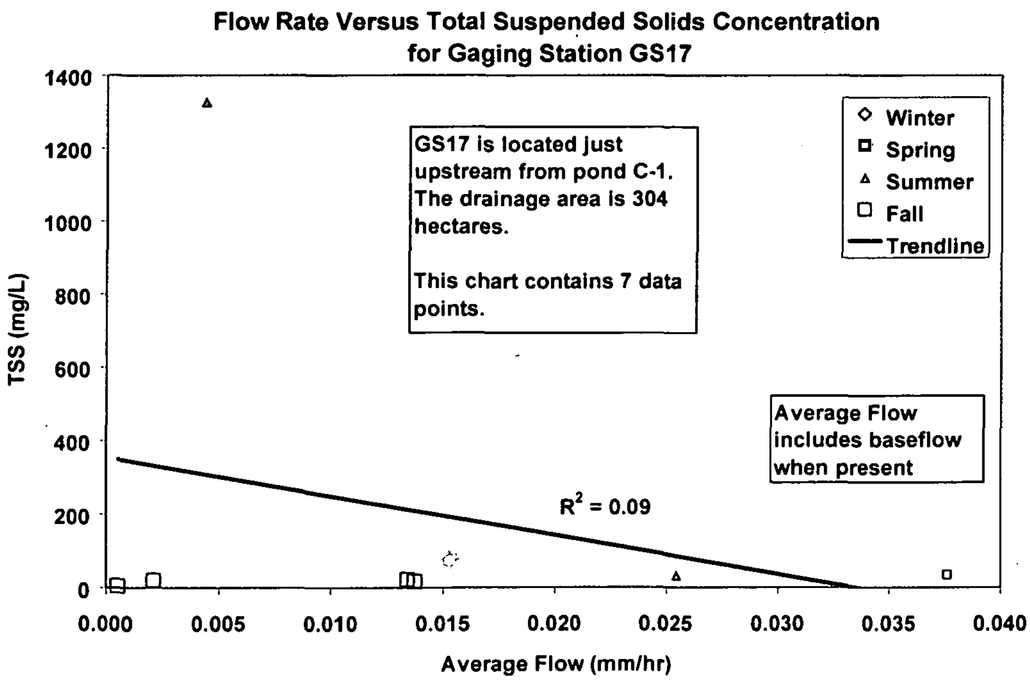

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Figure A-22. Comparison of TSS Data and Average Flow for GS21

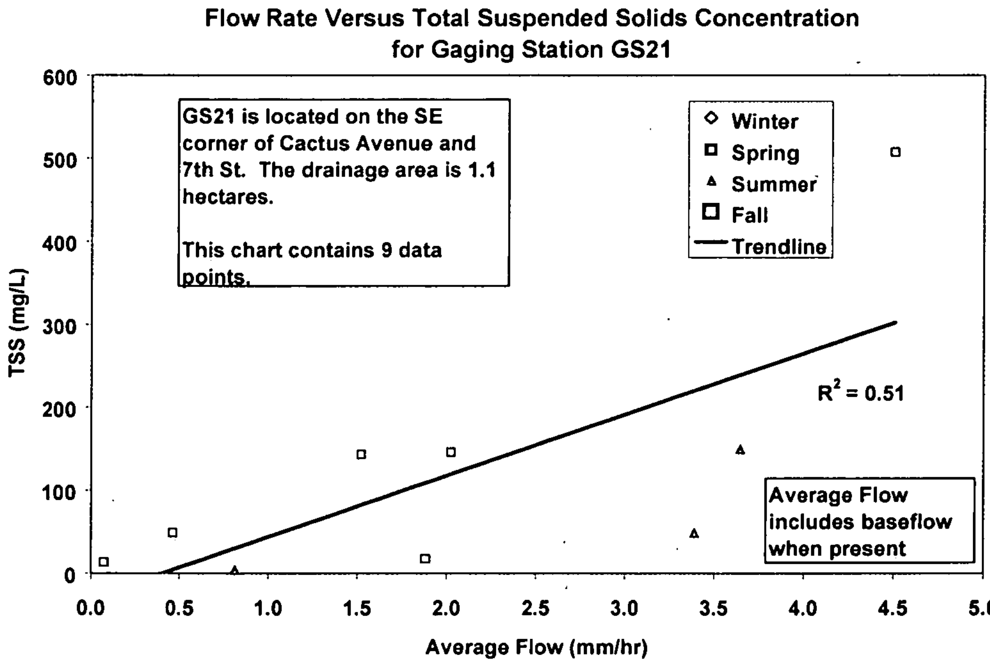
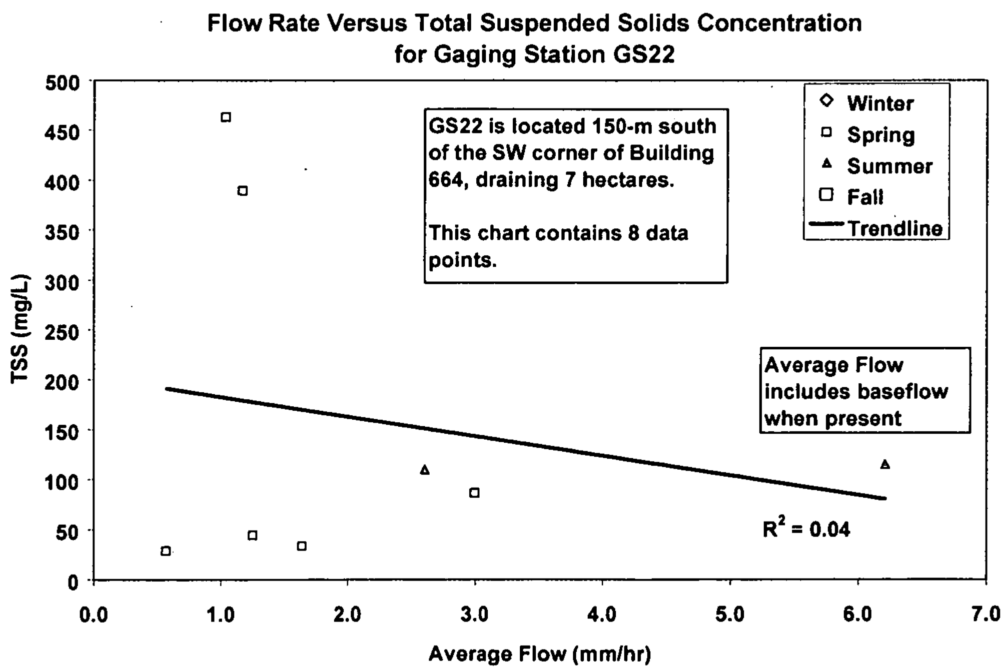


Figure A-23. Comparison of TSS Data and Average Flow for GS22



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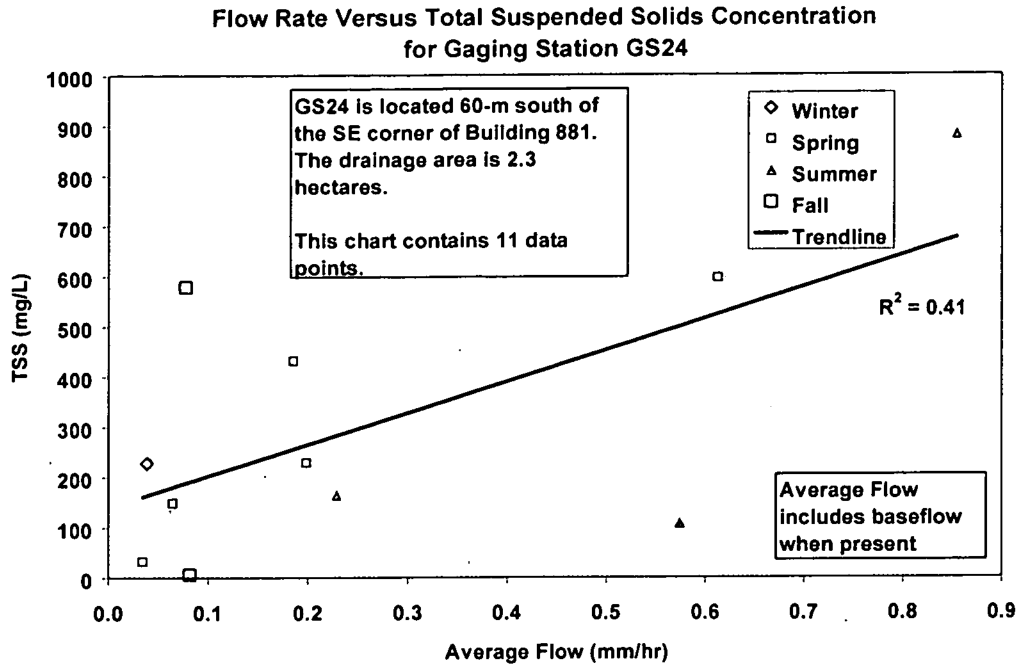

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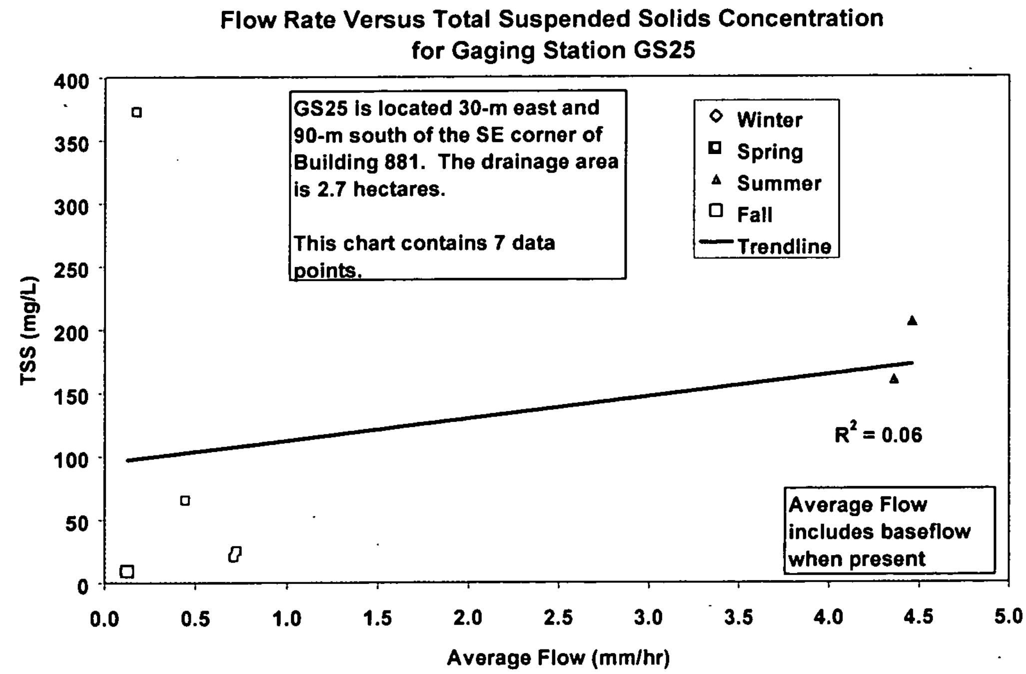

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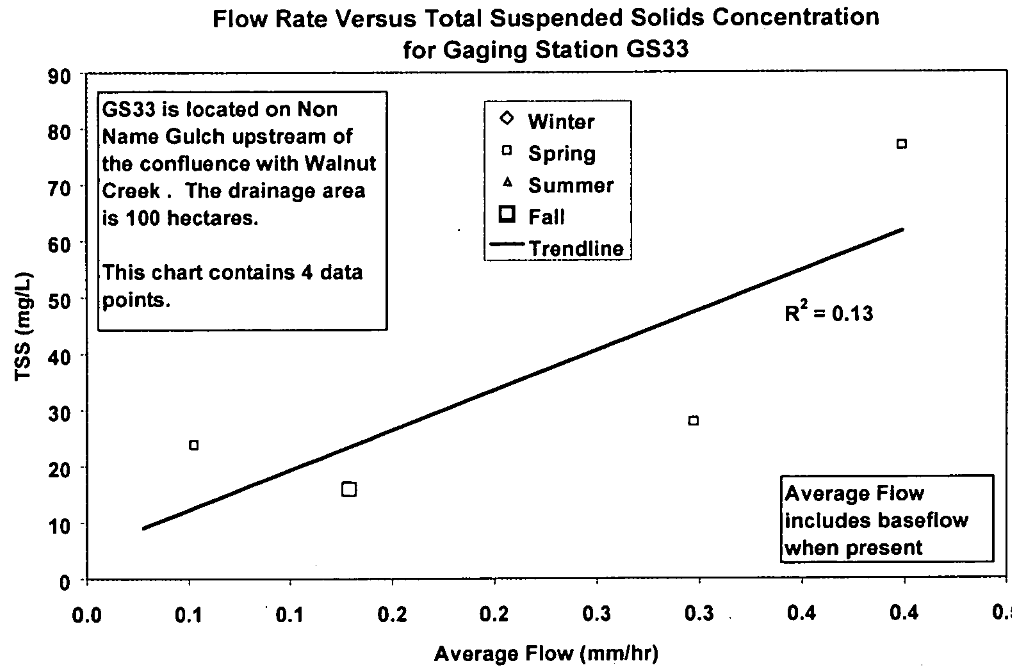

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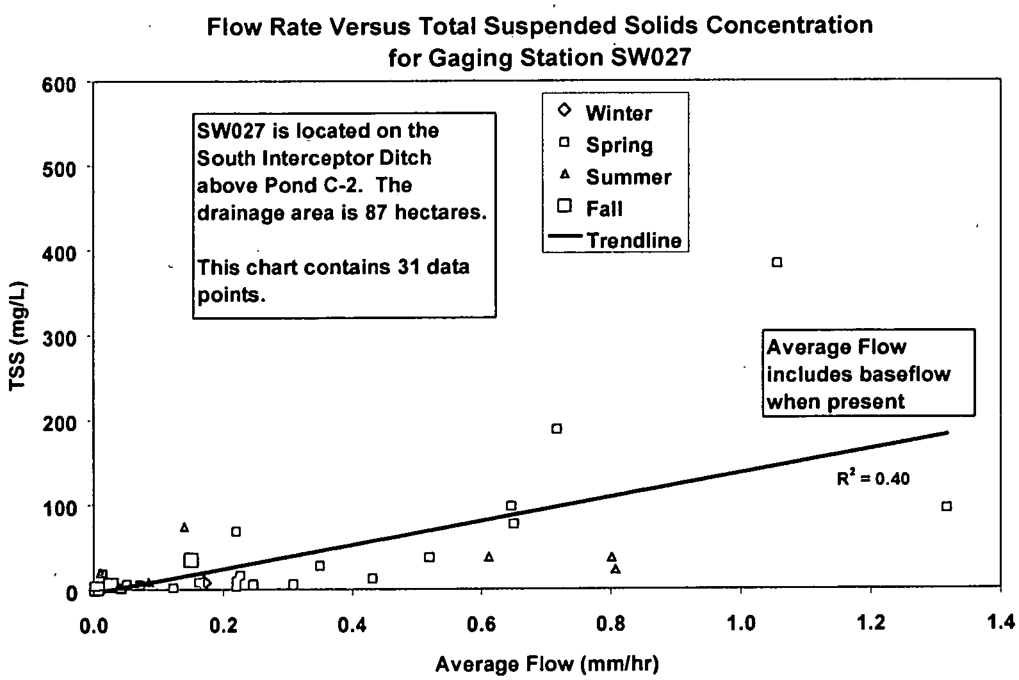

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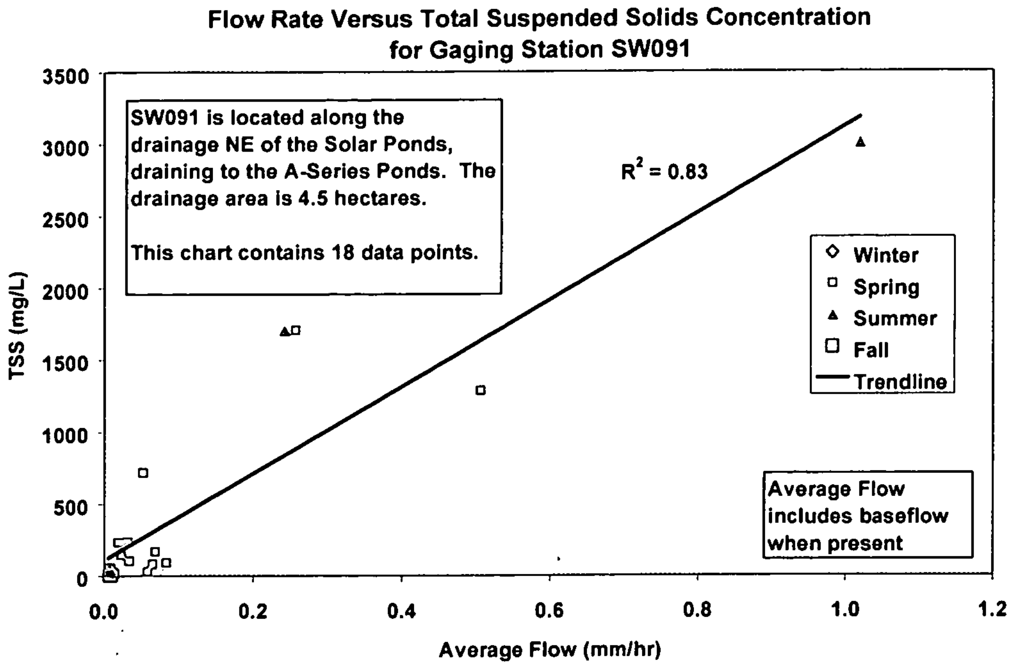

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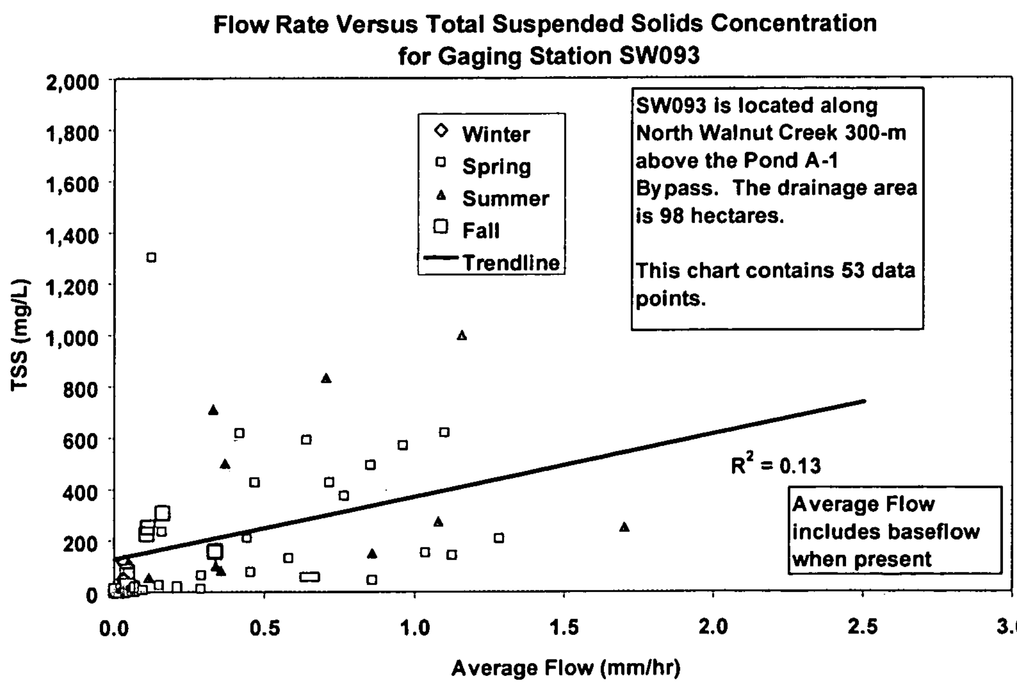

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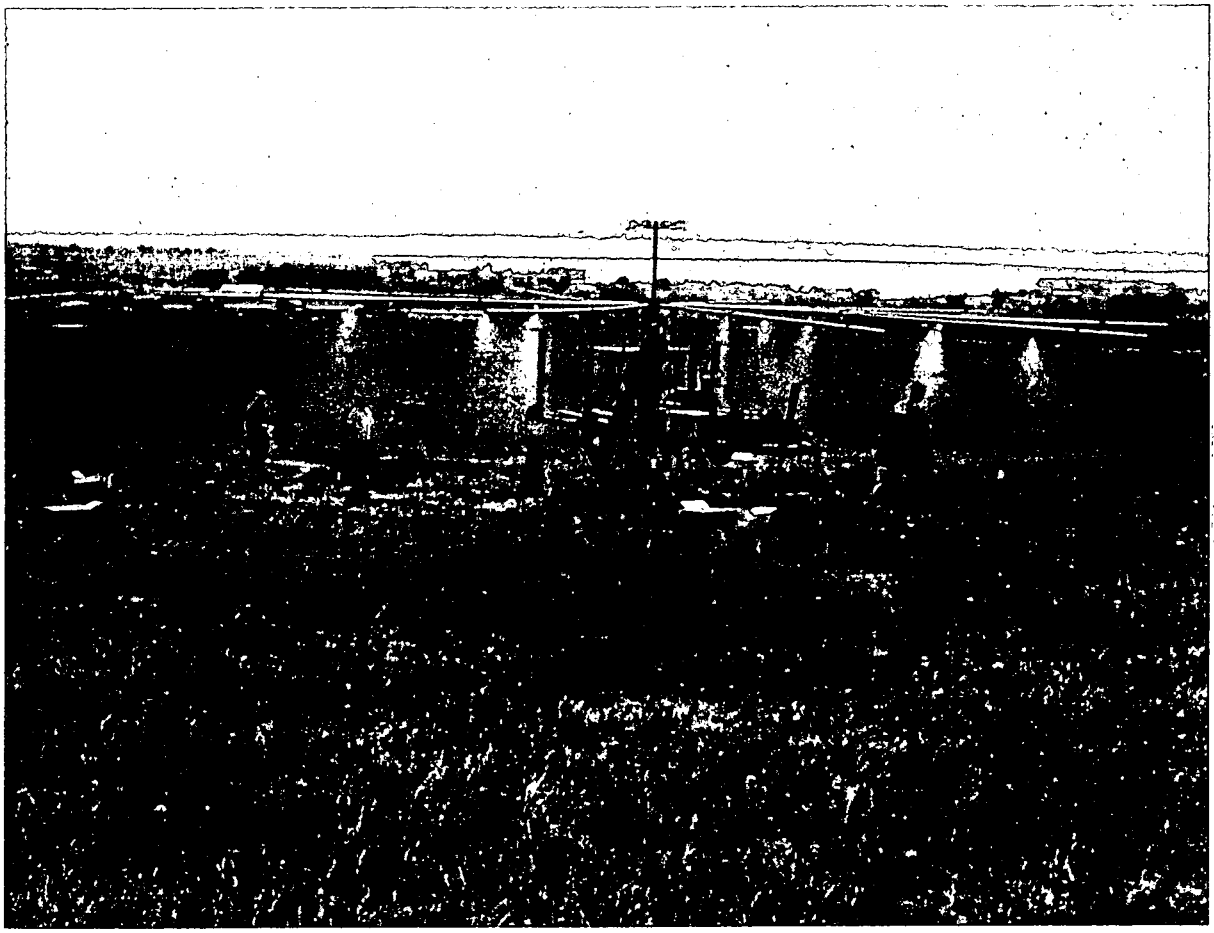

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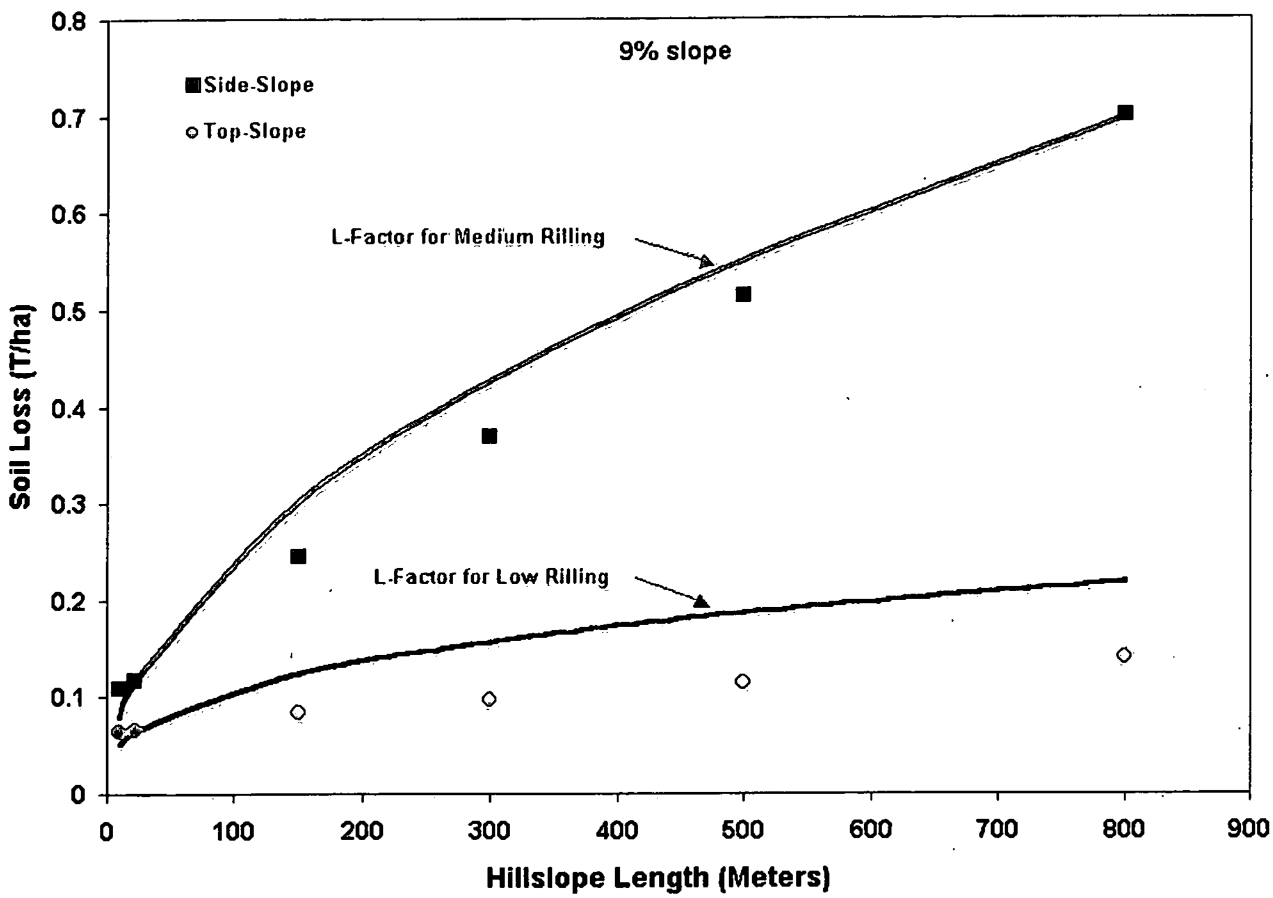

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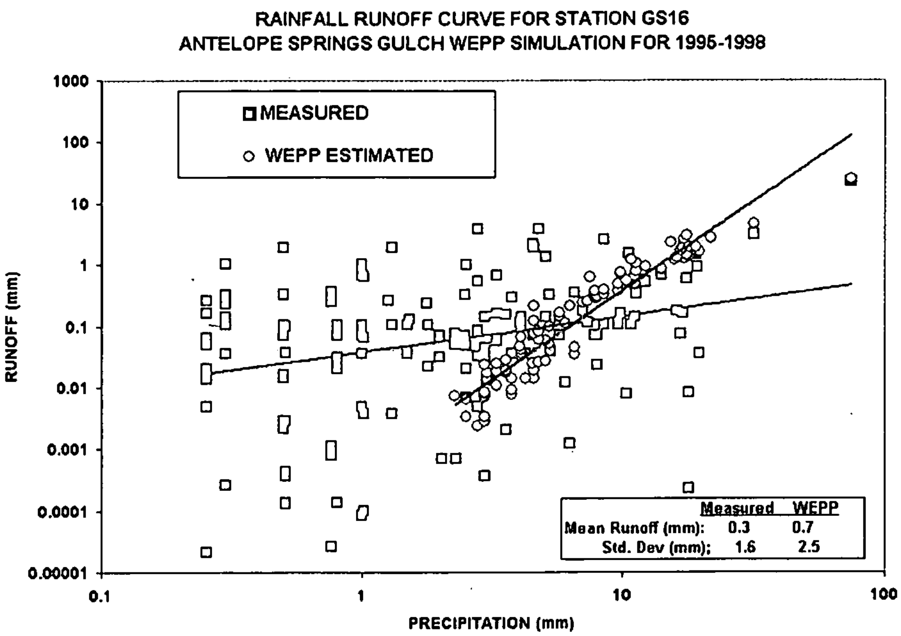

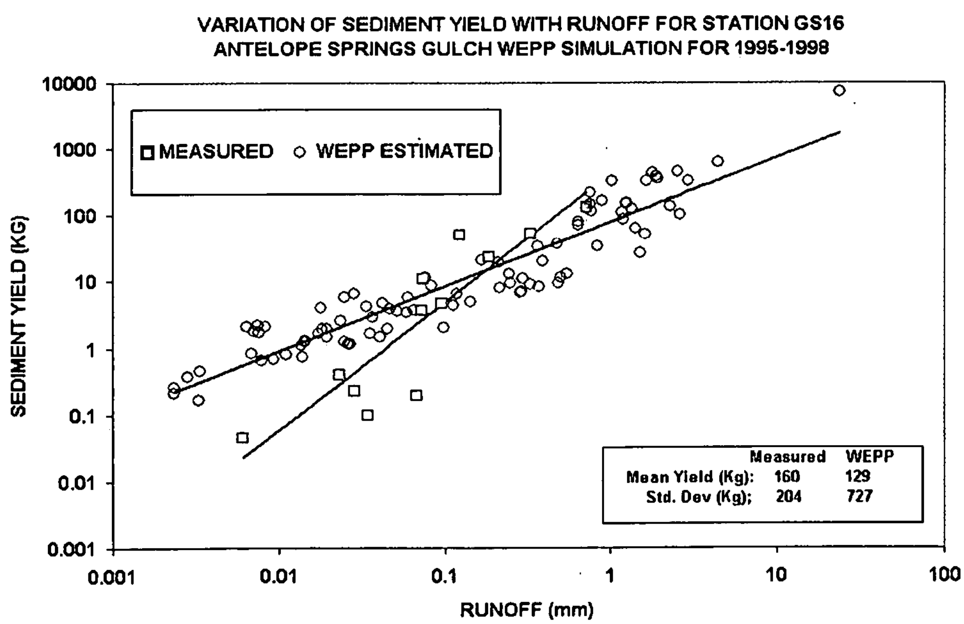

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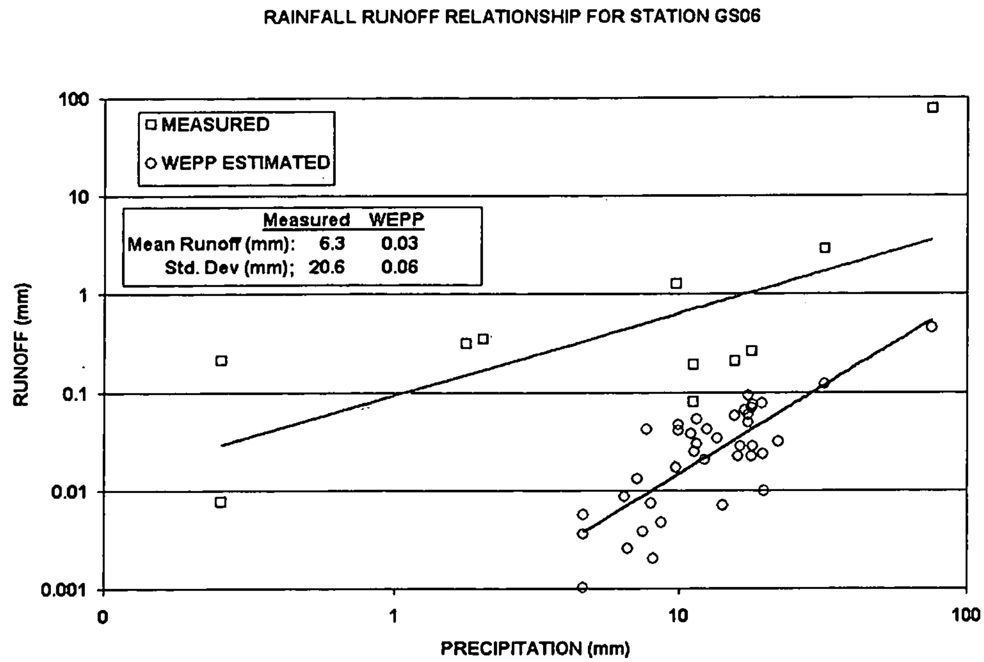

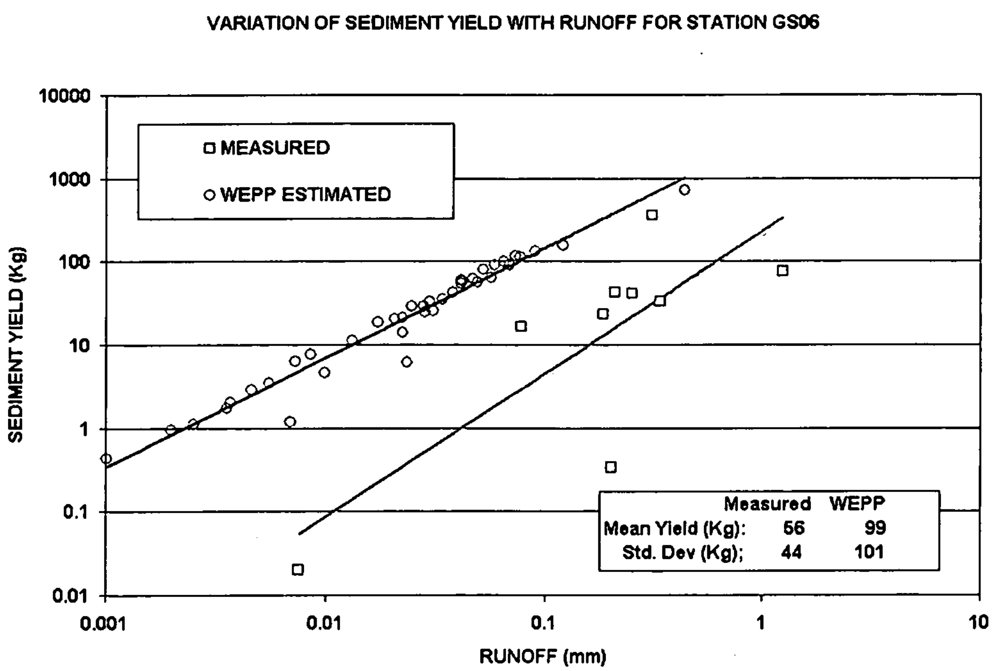

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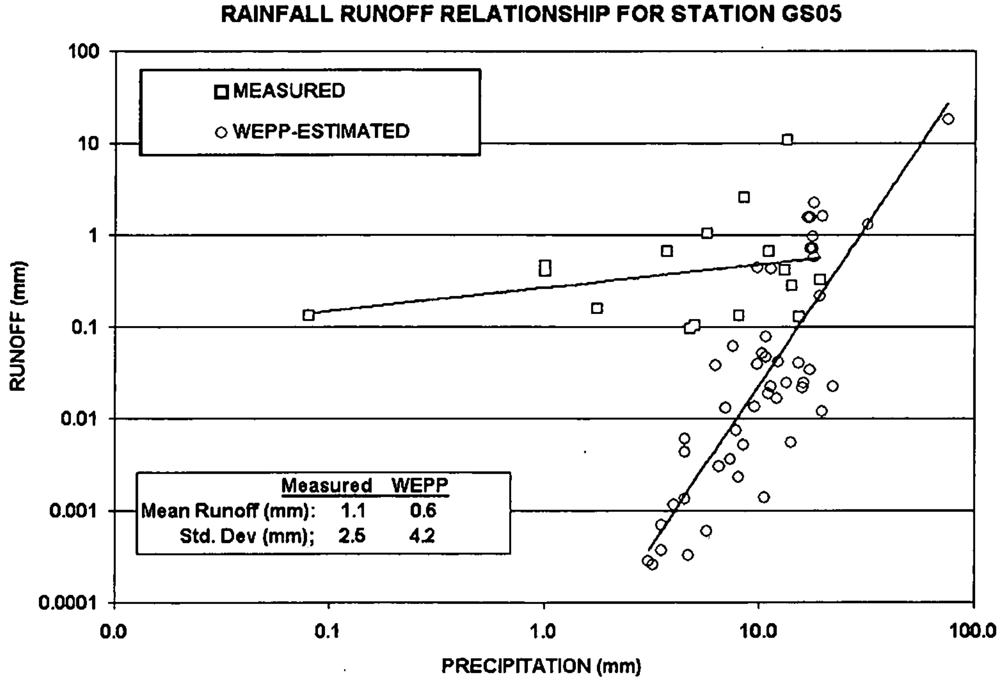

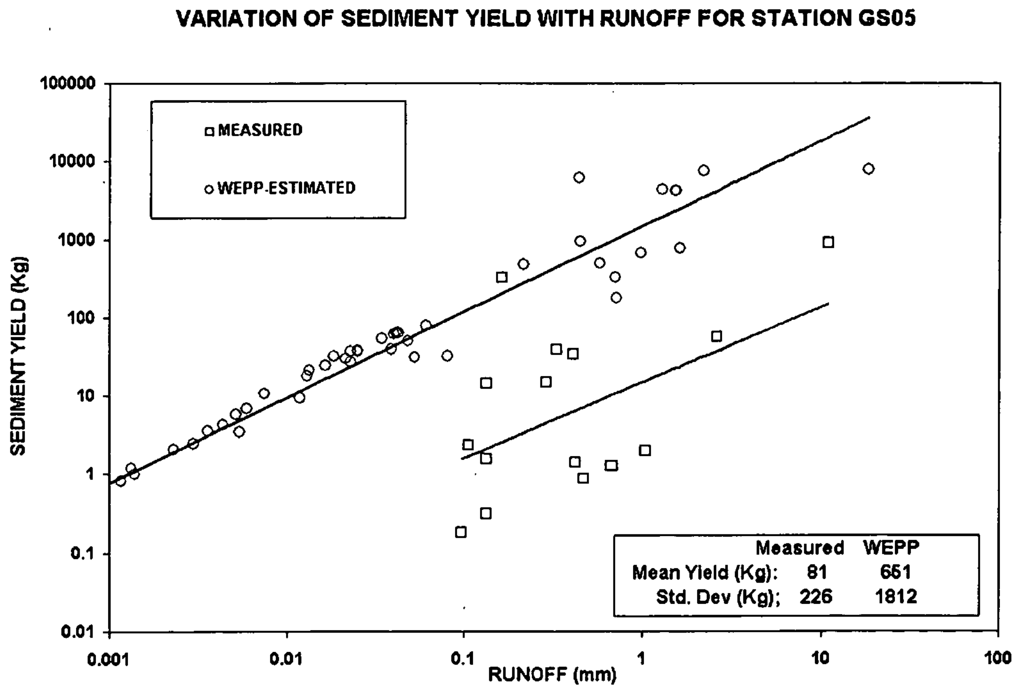

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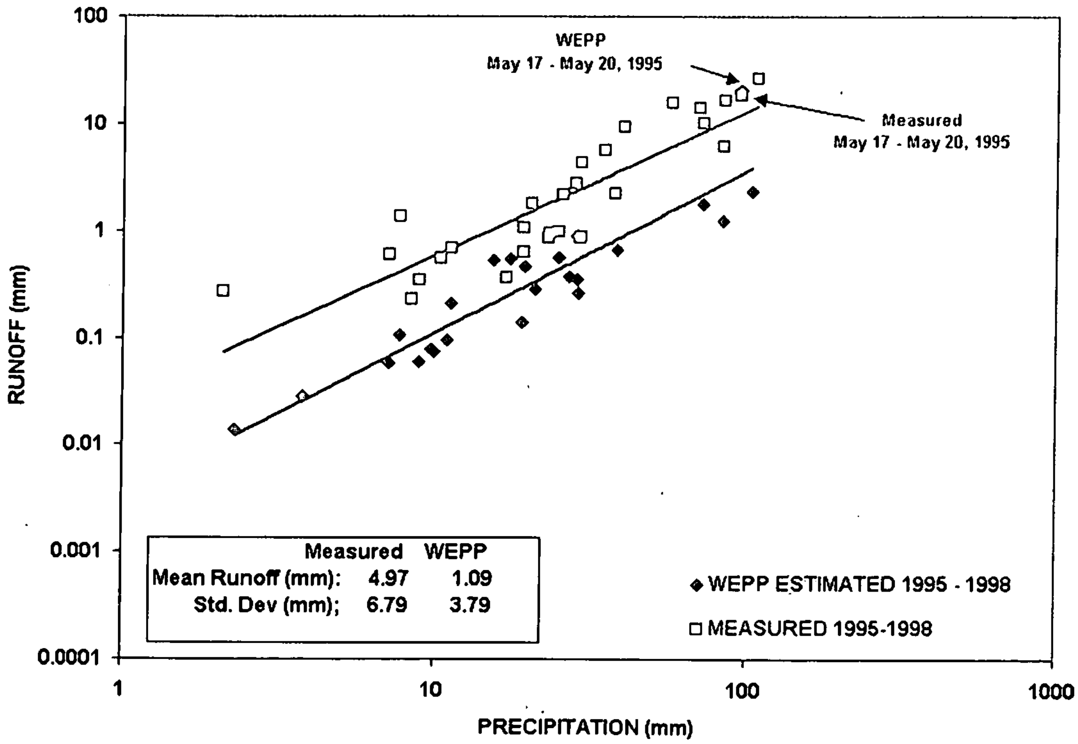

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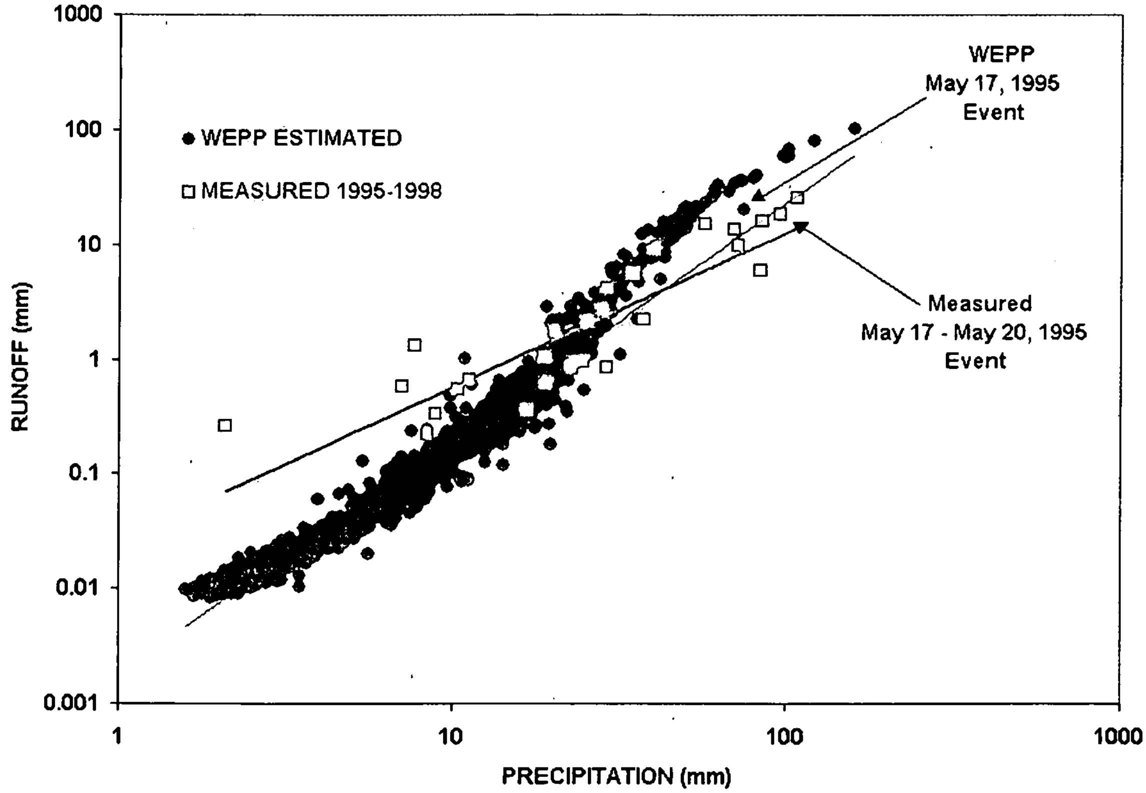

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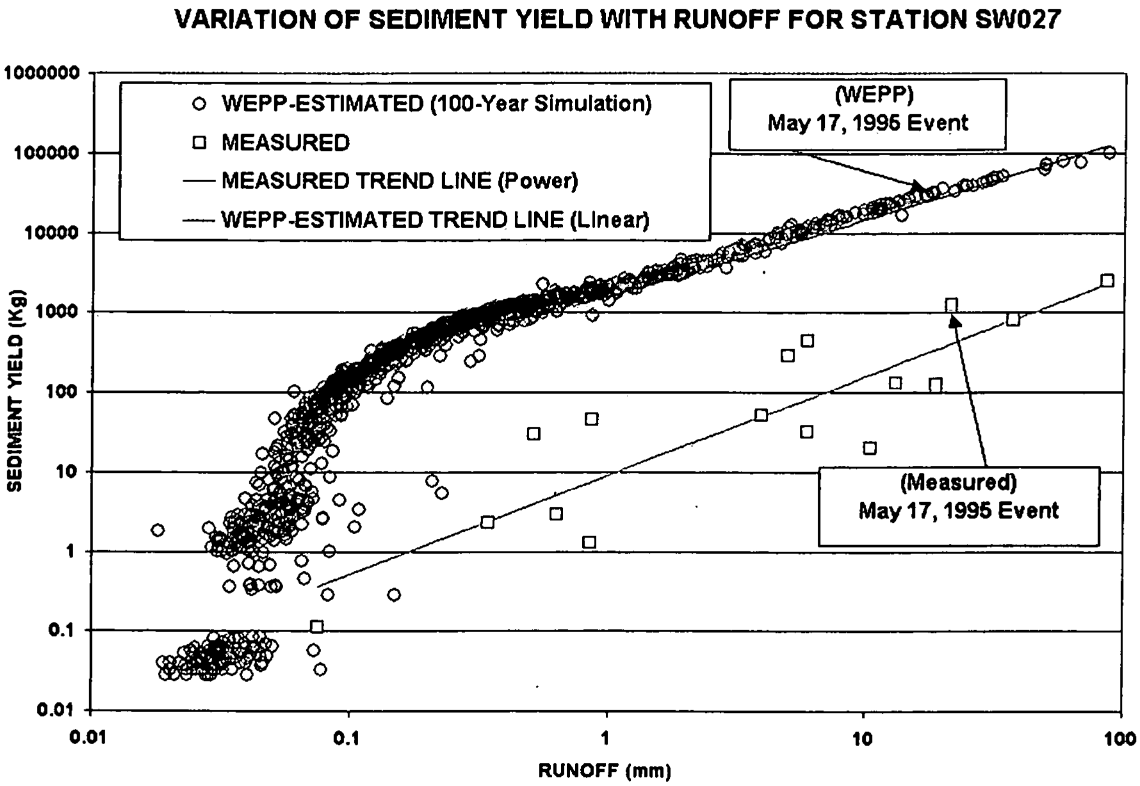

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B.1 Overview

Geostatistical analyses were performed on the plutonium (Pu-239/240) and americium (Am-241) sample data for surface soils at the Rocky Flats Environmental Technology Site (RFETS or Site). Geostatistical analyses, including variograms and kriging, are commonly used approaches when sample data exist in a large spatial area, such as the RFETS (Myers, 1997). Spatial data require special analytical techniques to extract the maximum amount of information available from the data and to minimize the uncertainty associated with concentration estimates and contaminant distribution maps. Geostatistical techniques have proved to be especially appropriate in the analysis of spatial data and in the assessment of uncertainty. Details of the geostatistical analyses performed for the erosion and sediment modeling effort appear in the following sections.

A total of 2,468 Pu-239/240 and 2,262 Am-241 surface soil samples were used to evaluate actinide concentrations across the Site. The data sets include samples dating from June 1991 through September 1999 and incorporate samples analyzed by both laboratory and field High Purity Germanium (HPGe) spectrometry techniques. Pu-239/240 sample concentrations ranged from non-detectable to more than 150,000 picoCuries per gram (pCi/g). Geostatistical analysis indicates that Pu-239/240 concentrations are below 5 pCi/g over most of the Site; however, extreme values occur at the 903 Pad, and high concentrations exist to the east of the 903 Pad. These values compare with typical background fallout levels in the Front Range of 0.01 to 0.10 pCi/g for Pu-239/240 (EG&G, 1995). Am-241 concentrations range from non-detectable to more than 30,000 pCi/g and follow spatial distributions similar to the Pu-239/240 data.

This geostatistical analysis differs from previous geostatistical efforts in three main ways:

- The data sets used for the geostatistical analysis represent the largest, most complete, and most up to date sampling coverage of the Site;
- Variogram and kriging analyses were performed within sub-portions of the Site that reflect differing levels of sample and spatial variability; and
- Logarithmic transformation of the sample data values was not performed.

These differences are discussed in detail below.

B.2 Data Analysis

B.2.1 Types of Sample Data

The data used in the Site-wide analysis represent several sampling events and sample types. Sample types include the following:

- Grab samples;
- Corporate samples;
- Rocky Flats method;
- Colorado Department of Public Health and the Environment (CDPHE) Method; and
- HPGe samples.

The Rocky Flats method removes soil in a 10- by 10-centimeter (cm) square to a depth of 5 cm. Five square areas were combined to create a composite sample that represented the center of a sampling grid. The CDPHE method uses twenty-five 6-cm by 5-cm rectangles, which are 0.64 cm deep to form a composite sample. HPGe data represent surface soil surveys of actinide concentrations over a 10-meter (m) diameter circular area.

B.2.2 Variability of Sample Data

B.2.2.1 Sample Data Variability Due to Sample Support

As described in Section B.2.1, sample data were composed of differing physical sizes (areas or volumes). The physical size, shape, and orientation of a sample is referred to as the sample support (Pitard, 1993; Myers, 1997). Typically, samples with larger support have less variability than samples with smaller support. This support-related characteristic was observed in the three data types. Grab samples exhibited the greatest variability, composite samples showed less variability, and HPGe *in situ* survey data had the least variability. The variability of the various sample supports is also related to the spatial location of the differently sized supports. This spatial relationship is described in Section B.2.2.2.

B.2.2.2 Spatial Variability of Sample Data

The distribution of actinide concentrations in surface soils at the Site is relatively consistent in many areas but highly variable in others. Variability is especially high in areas known to be sources of Pu-239/240 and Am-241, such as the 903 Pad. In locations quite distant

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or upwind from the source areas, variability is relatively low. Because of this spatial variability, the data were separated into different spatial areas, called domains, for the geostatistical analysis.

Two domain areas were defined for the variogram analysis. The first domain is the 903 Pad and Site locations generally to the east and south of the pad. The northern boundary of this domain runs approximately parallel to Central Avenue, with the southern boundary running approximately west to east just south of the South Interceptor Ditch (SID). The eastern boundary is Indiana Street. Sample data in this domain show Pu-239/240 concentrations above 10 pCi/g for much of the area from the 903 Pad eastward to within 305 meters (m) (1,000 ft) of Indiana Street. Am-241 concentrations range between 1 and 5 pCi/g over much of the same area. Extreme actinide concentrations and concentration variability are exhibited at and around the 903 Pad, with generally decreasing concentrations to the east.

The second data analysis domain is the remainder of the Site. The remaining Site area contains sample concentrations mostly below 10 pCi/g and exhibits much lower spatial variability.

The Site-wide data indicated a highly skewed, log-normal-type distribution. These attributes are typical of environmental contaminant data, with a large number of the data showing low concentrations and a small number showing higher concentrations combined with a few extreme values. Data values at the Site span approximately eight orders of magnitude. Summary statistics for the Site sample data are shown in Table B-1.

Table B- 1. Summary Statistics for the Site Sample Data

STATISTIC	CONTAMINANT	
	Pu-239/240 (pCi/g)	Am-241 (pCi/g)
Minimum	0.0	0.0
Maximum	152,260	31,670
Mean	145.8	27.7
Variance	9,894,206	458,240
Standard Deviation	3146	677
Number of Sample Data	2468	2262
Median	1092	227
Coefficient of Variation	21.6	24.4

Note: Minimum Detected Activities (MDAs) vary for each sample

B.3 Variogram Analysis

Variogram analysis, or variography, is a fundamental step in a geostatistical analysis to quantify the degree of spatial variability of the contamination. Because significant spatial variation is exhibited by the sample data, variographic analysis was performed on the surface-soils data at the RFETS.

It has been widely documented in the earth and environmental sciences that nearby samples generally have concentrations more similar than samples that are further apart (Matheron, 1965; David, 1977; Isaaks and Srivastava, 1987; Litaor, 1995; Myers, 1997). In statistical terms, this means that the samples are correlated. Correlation is useful information that can be captured and used to minimize estimation errors of contaminant concentrations.

Variogram analysis captures correlation information by comparing sample data at different distance intervals. Generally, as the distance between two or more samples increases, the variability also increases with a corresponding decrease in the correlation. Eventually, at some distance, the variability reaches a maximum, indicating that correlation between samples no longer exists and that samples are independent.

Variography was performed on the data in the Site and plume domains separately. The reason for this is the substantial difference in the spatial data variability between the two domains as well as the various sample supports. Because the HPGe data are less prone to sampling and sub-sampling errors due to the larger sample support size (Pitard, 1993), only the HPGe data were used in the Pu-239/240 variogram analysis for the plume area. Due to lower Am-241

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concentrations and lower variability, data from the 903 Pad as well as the HPGe data were used for the Am-241 variograms.

Experience has shown that the spatial variability can differ dramatically in different directions; thus, it is appropriate to investigate several directions during the variogram analysis. Situations where the variability is equal in all directions produce variograms that are said to be isotropic, and the spatial continuity can be visualized as circular. Situations where variability is not equal in all directions produce anisotropic variograms, with a short and long axis of spatial continuity, and can be visualized as elliptical in nature. Anisotropic variograms were found for both Pu-239/240 and Am-241 data in both domains.

Within each area (plume and Site), five different directions were analyzed: north-south, northeast-southwest, east-west, northwest-southeast, and omni-directional (all directions simultaneously). The spatial variability in these five directions was analyzed for both Pu-239/240 and Am-241.

Due to the high variability in the data, several types of variogram analyses were performed. Different types of variogram analyses can often mitigate the influence of the high variability of the sample data values. For data in the Site and plume domains, variograms for untransformed data were analyzed. In addition, general relative variograms, local relative variograms, and logarithmic variograms were also run in the Site and plume domains. The variogram graphs indicated that the best results were for the untransformed data.

Variogram graphs for the Site domain appear in Figures B-1 and B-2 for Pu-239/240 and Figures B-3 and B-4 for Am-241; variogram graphs for the plume domain appear in Figures B-5 and B-6 for Pu-239/240 and Figures B-7 and B-8 for Am-241. Variogram graphs in the plume domain exhibit structure similar to that found at other environmental sites where there is a small, concentrated contaminant source and where wind is a significant dispersion mechanism. For example, lead smelters typically show very high concentrations close to the smelter, combined with down-wind contamination dispersion. In such cases, the variogram graphs tend to rise very quickly from the origin for a short distance, then rise more gradually for a longer distance (Myers, 1985). This type of feature was observed in the plume domain variography.

Once the variogram graphs were obtained, a mathematical model was fit to each directional variogram graph. The mathematical model describes the variability and correlation of the sample data as the distance between samples increases. This correlation is used in the kriging process. Numerous types of mathematical equations are available for variogram modeling. For the Site and plume variograms, the commonly used spherical model was selected to represent the graphs. Table B-2 lists the variogram parameters selected for the long and short axes of spatial continuity and the direction of these axes. The equation for the spherical model appears below:

$$\gamma(h) = C_o + C\left[\frac{3}{2}\frac{h}{a} - \frac{1}{2}\frac{h^3}{a^3}\right]$$

where:

$\gamma(h)$	=	variance at distance h (m);
C_o	=	nugget effect;
C	=	spherical component;
a	=	range of influence (m); and
Sill	=	$C_o + C$.

Table B- 2. Selected Variogram Models

CONTAMINANT	DOMAIN	VARIOGRAM PARAMETERS							
		C_o	C	a_{min} (ft)	a_{min} (m)	Direction	a_{max} (ft)	a_{max} (m)	Direction
Pu-239/240	Site	0.2 0	1.55	500	152	E-W	700	213	N-S
	Plume	0.0	7000	125	38	N-S	175	53	E-W
Am-241	Site	0.0	5.8	175	53	NW-SE	275	84	NE-SW
	Plume	25	70	250	76	N-S	375	114	E-W

The nugget effect indicates that there is variability even at a distance of zero, demonstrating that extreme variability may occur over very short distances. It is also an indication of sampling and analytical error. No nugget effect was observed for the Pu-239/240 plume and Am-241 Site data sets. Relatively small nugget effects (approximately 10 to 25 percent of the sill value) were observed for the Pu-239/240 Site and Am-241 plume data sets.

The results of the variogram study were similar to the results obtained in previous studies. The general shapes of the variograms were consistent for all three studies, exhibiting good spatial correlation structure with relatively low nugget effects, if any. This study used shorter lag distances to classify sample distance relationships. By using shorter lag distances, shorter ranges were observed. Use of logarithmically transformed data in previous studies may have also contributed to longer ranges.

Shorter ranges, however, offered the opportunity to gain a more precise definition of the variogram at short distances. This resolution increase was considered desirable at the 903 Pad and the area to the east of the pad (the areas of highest contamination and variability), since many of the sample data are separated by relatively short distances.

In summary, both Pu-239/240 and Am-241 data produced variograms exhibiting significant spatial correlation in both the Site and plume domains. The raw, untransformed data were used to produce the variograms, and logarithmic transformation was not necessary.

B.4 Kriging

Existing sample data must be used to estimate the actinide concentrations at locations that have not been sampled, because it is not affordable or feasible to sample every location at the Site. Various computerized estimation techniques have been developed for this purpose. The geostatistical technique known as kriging was selected for estimation of the Pu-239/240 and Am-241 sample data at the RFETS.

Kriging offers many advantages over other estimation techniques. Among these is the fact that kriging is a best linear unbiased estimator (BLUE). A BLUE simply means that the estimation is done with the minimum amount of error. Other BLUE exist in statistical analysis, including the well-known linear regression equation. Kriging is a BLUE that has been specially adapted to handle spatial data estimation. As indicated, kriging is unbiased, meaning that the technique does not systematically over- or underestimate the soil contaminant concentrations.

Kriging uses variogram models, such as those in Table B-2, to optimize the estimation and to minimize the estimation errors. During the kriging process, the kriging program searches for samples that are closest to the unsampled area being estimated. Kriging recognizes that samples closest to the area being estimated should be given more weight than samples located further away. The kriging program calculates the optimal weighting system for the available samples and derives an optimal estimate of the actinide concentration at the unsampled location.

As with the variogram, kriging is sensitive to areas of high and low variability, as well as areas where sample concentrations vary dramatically over short distances; therefore, several kriging domains were established. The major domain areas, the Site and the plume, were retained but were further subdivided. Within the Site domain, an area to the north and west of the 903 Pad was defined for kriging. The impact of actinide contamination in this area is thought to be significantly less than in the areas to the east of the 903 Pad. This domain was kriged by using samples in the Site domain, but not samples from the plume area, which had actinide concentrations orders of magnitudes higher. The remainder of the Site area was kriged as a single unit. The Site variogram models for Pu-239/240 and Am-241 were used in kriging.

Within the plume domain, the 903 Pad was defined as a separate domain for kriging. The concentrations and variability of the sample data on the pad are more extreme than at any other portion of the Site. As such, the 903 Pad was kriged using sample data exclusively from the 903 Pad area and a limited number of samples from the Site domain. The Trench 1 area, also within the plume domain and located north and east of the 903 Pad, has undergone remediation and resurfacing. No actual kriging was performed in the Trench 1 area. The remainder of the plume domain was kriged using the sample data from the plume domain. Both the 903 Pad and plume domains were kriged using the plume variogram models for Pu-239/240 and Am-241.

The kriging in each of the five domains of the Site was done using ordinary kriging of block areas. Block kriging, on the other hand, integrates the estimate of the actinide concentration over the area of the block. Blocks used for kriging measured 22.8 m x 22.8 m (75 ft x 75 ft) in all Site domains. Each block represents approximately 523 square meters (m^2) (5,625 square feet [ft^2]) in area, or approximately 0.05 hectares (ha) (0.13 acres [ac]).

Visual representations of the block kriging estimates for Pu-239/240 can be seen in Figure B-9. Each block has been shaded with a color representing the estimated average concentration over the block area. Ten concentration categories (pCi/g) have been established for the map display: less than 0.1; 0.1 to 1.0; 1.0 to 5.0; 5.0 to 10; 10 to 25; 25 to 100; 100 to 252; 252 to 1,492; 1,492 to 10,000; and greater than 10,000. A similar representation of Am-241 block concentrations can be seen in Figure B-10, where the concentration categories (pCi/g) correspond to the values of less than 0.1, 0.1 to 1.0, 1.0 to 5.0, 5.0 to 10, 10 to 38, 38 to 215, 215 to 500, and greater than 500.

B.5 Results

The block maps shown in Figures B-9 and B-10 exhibit some distinct features. The site domain is generally characterized by relatively low actinide concentrations. An exception to this appears in the Industrial Area, at the 903 Pad, where sample data indicated both Pu-239/240 and Am-241 contamination. Actinide contamination levels generally decrease to the east and

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southeast of the 903 Pad. Concentrations continue to decline within the plume domain to the site boundary at Indiana Street, where the kriging was truncated.

Some notable artifacts exist in Figures B-9 and B-10, which are related to the sampling density and sampling pattern used at the RFETS. In Figure B-9, an area of approximately 202 ha (500 ac) on the west side of the site exhibits Pu-239/240 concentrations between 0.1 and 1.0 pCi/g. This feature is the result of limited sampling in the area. Approximately four samples are responsible for this artifact. These samples are located along the road running north then northeast from the Raw Water Reservoir. No other samples exist between these samples and the site boundary on the west. As such, the concentrations of these samples are extended westward.

Similarly, large areas south of the RFETS facility exhibit Pu-239/240 concentrations between 0.1 and 5.0 pCi/g. These areas were estimated using a limited number of samples, approximately 10 to 20. A line of four samples running east-west exists approximately 914 m (3,000 ft) north of the site boundary to the south. A single sample exists south of the site boundary. These five samples are highly influential in the estimated concentrations shown on the map, representing approximately 202 ha (500 ac). A smaller area, representing approximately 40 ha (100 ac), exists south of the RFETS facility in Figure B-10. This artifact results for the same reason as described for Pu-239/240 in Figure B-9.

Table B-3 lists the estimated areas covered by the various Pu-239/240 concentration categories. Table B-4 lists the estimated areas covered by the various Am-241 concentration categories.

Table B- 3. Breakdown of Areas with Estimated Pu-239/240 Concentrations

Pu-239/240 CONCENTRATION (pCi/g)	ESTIMATED NUMBER OF HECTARES	ESTIMATED NUMBER OF ACRES
< 0.1	239.2	591
0.1 – 1.0	1489.7	3,681
1.0 – 5.0	443.5	1,096
5.0 – 10.0	135.2	334
10 – 25	106.8	264
25 – 100	84.2	208
100 – 252	7.7	19.1
252 – 1,429	4.4	10.8
1429 – 10,000	1.5	3.7
> 10,000	0.5	1.2

Table B- 4. Breakdown of Areas with Estimated Am-241 Concentrations

Am-241 CONCENTRATION (pCI/g)	ESTIMATED NUMBER OF HECTARES	ESTIMATED NUMBER OF ACRES
< 0.1	1778.6	4,395
0.1 – 1.0	545.5	1,348
1.0 – 5.0	165.9	410
5.0 – 10.0	9.9	24.4
10 –38	9.1	22.6
38 – 215	2.8	6.8
215 – 500	0.5	1.3
> 500	0.9	2.3

B.6 Methodology for Creating Erosion Maps

A methodology was developed by Destiny Resources and Wright Water Engineers to transform the linear (one-dimensional) output from the Watershed Erosion Prediction Project (WEPP) model into two-dimensional space for displaying on a map. The following protocol describes this methodology.

Step 1

The linear set of control points (slope transects shown in the main report, Figures 7a, 7b, 8 and 9), created to develop the slope input data for WEPP, were associated with the WEPP model erosion output. The control points were replicated, resulting in multiple sets of identical points across each Overland Flow Element (OFE). The number of replications depended on the size and shape of the OFE represented.

Step 2

Erosion output from each OFE was analyzed to determine distances down-slope at which there were significant changes in the amount of predicted erosion. Those points, representing distances down the slope from the top of the OFE, were transferred to a file. A program was run to extract the corresponding replicated points from Step 1 for each OFE. The file of extracted control points is the control framework for conversion of the one-dimensional data to two-dimensional space.

Step 3

Transformation of the points into two-dimensional space was accomplished using a geographic information systems (GIS) technique called Triangular Irregular Networks (TINs),

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where planar surfaces are formed between each control point. OFE outlines are entered as boundaries, resulting in the TIN process only performing the calculations OFE-by-OFE, without taking into account the values in adjacent OFEs. The resulting surface is then converted into a grid sampled at one- to two-foot intervals.

Step 4

For the final conversion to two-dimensional space, each of 256 shade-colors were assigned erosion values, ranging from dark blue for the greatest levels of deposition to dark red for the greatest level of erosion, with white assigned to areas where no deposition or erosion is taking place. Using these shade-colors, the erosion grid was transformed into a colored surface that was mapped.

The result was a soil mobility map that visually represents the results of the WEPP model. Two types of maps were produced for the current report. One map represents the 100-year annual average erosion predicted by the WEPP model (main report Figure 17). This map does not display the amount of erosion occurring in any one year. Rather, it depicts an annual average erosion rate that can be expected to occur for years with large storms and wet periods over a 100-year period. Another set of maps was created to represent soil movement due to a 6-hour, 100-year storm (main report Figures 18-21), as described in the Results section of the report.

B.7 Modeling Actinide Movement by Soil Erosion Processes

As a follow-up to mapping the WEPP-estimated soil erosion and deposition across the Site, the Actinide Migration Evaluation (AME) team predicted the movement of actinides due to soil erosion. This task is the final step for predicting actinide loading to surface water. Soil movement (erosion) alone is not a good estimator of the amount of actual actinide movement across the Site due to the variability in the distribution of actinides in Site soils (refer to Figures B-9 to B-10). The spatial distribution of actinide soil contamination must be combined with the soil erosion to estimate actinide movement. The results obtained from this task can be used to determine soil remediation levels that are protective of surface-water quality with respect to Site standards and action levels. The modeling activity described below can be thought of as overlaying the soil activity isoplot maps soils (Figures B-9 and B-10) on the erosion maps (Figures 7a, 7b, 8 and 9 of the main report) and calculating the quantity of actinide that moves down the hillslopes.

The methodology for modeling actinide movement by soil erosion processes is described below.

Step 1

Detailed erosion data were captured from the WEPP model output. These data are the estimated amounts of soil erosion/deposition at each one percent interval down each OFE. Therefore, 100 values indicating the amount of erosion or deposition at equally spaced intervals down each OFE are obtained.

Step 2

Data from Step 1 were loaded into GIS and converted into intervals of distance down the OFE (or layers). Depending on the width and complexity of each OFE, between one and fifteen points on the OFE were selected to constitute a layer. The actinide activities were determined from the isoplot grid at each point in the layer. From those points, an average activity was determined and assigned to the layer. This process was repeated for each layer in the OFE and for each OFE in each hillslope.

Step 3

Using a combination of the erosion data from Step 1 and the average activities for each layer from Step 2, a simple model was run, which developed an accounting of the accumulated amount of soil loss down the OFE and the average actinide activity associated with that soil. The model ran its computations layer by layer down the OFE and OFE by OFE down the hillslope. Output from this model included 1) the sediment yield leaving the hillslope; 2) the average actinide activity of the sediment leaving the hillslope; and 3) the total actinide yield leaving the hillslope. The resulting soil loss values were cross-checked with the amount calculated by the WEPP model to confirm that the GIS model produced accurate results.

B.8 Modeling Actinide Concentrations in Surface Water

To predict surface water concentrations of Pu-239/240 and Am-241 in each drainage (Walnut Creek, Woman Creek, the South Interceptor Ditch, and Mower Ditch), models for every drainage were developed in Microsoft® Excel to merge WEPP and the Hydraulic Engineering Center Sedimentation in Stream Networks (HEC-6T) model results with actinide soil activity data. The surface-water actinide concentration models for each drainage were duplicated and input with storm-event-specific data to create unique surface-water actinide concentration models for each drainage and each storm. Each of these unique surface-water actinide concentration models requires input data from sources outlined in Section B.8.1.

B.8.1 Surface Water Actinide Concentration Model Inputs

The following list describes the various input data required by each of the unique surface water-actinide concentration models:

1. WEPP hillslope erosion data provide the predicted mass yields for five ranges yielded from each hillslope for a specific storm event. These masses for the five particle size ranges are redistributed into the nine particle sizes used by the HEC-6T model (see Section 6.0 of the report).
2. HEC-6T sediment discharge data provide the predicted mass of material, for nine separate particle size ranges, yielded from each channel reach for a specific storm event.
3. HEC-6T water discharge data provide the predicted volume of water yielded from each channel reach for a specific storm event.
4. Output data from a (GIS) model provide estimated levels of Pu-239/240 and Am-241 in the soil (pCi/g) that has been eroded and discharged at the bottom of each hillslope (see description of the GIS model in Section B7). Again, these data are storm-event-specific.
5. Unitless "enrichment factors" were calculated to quantify the increased or decreased actinide activity level factor associated with a specific particle size range relative to a unit mass of typical hillslope material composed of mixed particle sizes (as provided by the GIS model described in point 4 above). These enrichment factors are the same for each watershed model. They were calculated using the Pu-239/240 and Am-241 versus mass distributions from the Colorado School of Mines (CSM) study (utilizing four particle size ranges) to redistribute the Pu-239/240 and Am-241 among HEC-6T's nine particle size ranges (RMRS, 1998d). Section B-10 describes the comparison of WEPP-estimated and measured particle size distributions and the particle size distribution of Pu-239/240 and Am-241 in Site soils. For each of the nine particle size ranges, the percent of total activity divided by the percent of total mass results in an enrichment factor that quantifies the relative affinity of Pu-239/240 and Am-241 for specific sizes of particles. An enrichment factor greater than one

indicates that a unit mass of that particular particle size has an actinide concentration (activity per unit mass) that is greater than that of the "bulk" mixed size material. Similarly, an enrichment factor less than one indicates the specific particle size has an actinide concentration (activity per unit mass) that is less than that of the "bulk" mixed size material. Enrichment factors calculated and applied to this model are listed in Table B-5.

Table B-5. Particle Size Enrichment Factors

Particle Size Lower Bound (microns)	Particle Size Upper Bound (microns)	Particle Size Mass Distribution Cum Fraction	Particle Size Mass Fractions by Size Class	Am-241 Distribution Cum %	Fraction by Size Class	Am-241 Enrichment Factor	Pu-239/240 Distribution Cum %	Fraction by Size Class	Pu-239/240 Enrichment Factor
0	4	0.029	0.029	0.047	0.047	1.615	0.045	0.045	1.553
4	8	0.042	0.013	0.069	0.022	1.705	0.067	0.022	1.682
8	16	0.124	0.082	0.164	0.095	1.157	0.146	0.079	0.957
16	32	0.235	0.111	0.295	0.131	1.176	0.256	0.111	0.998
32	62	0.341	0.106	0.418	0.124	1.166	0.360	0.103	0.974
62	125	0.455	0.114	0.551	0.133	1.165	0.471	0.111	0.977
125	250	0.576	0.121	0.674	0.123	1.017	0.587	0.116	0.960
250	500	0.719	0.142	0.782	0.108	0.755	0.726	0.138	0.971
500	1,000	0.860	0.141	0.891	0.110	0.776	0.863	0.137	0.972
1,000	2,000	1.000	0.140	1.000	0.109	0.776	1.000	0.137	0.979

The uncertainty associated with the enrichment factors can greatly affect the range of predicted actinide concentrations in surface water. Although the uncertainty in determination of the enrichment factors for the parent soils has been quantified by CSM (see Appendix D), there is a lack of understanding of how the enrichment factors may change in the sediment delivered to surface water at the toes of the hillslopes. The uncertainty in the enrichment ratios adds to the uncertainty of the estimates of Pu-239/240 and Am-241 in surface water as a result of erosion and sediment delivery estimates.

B.8.2 Surface Water Actinide Concentration Model

For each of the four drainages and for each storm event modeled, the calculations described in the following subsections were made to estimate the concentrations of both Pu-239/240 and Am-241 in surface water for every channel reach.

B.8.2.1 Calculate Sediment Inputs and Outputs by Channel Reach

The HEC-6T output provides the predicted mass of material, for nine separate particle size-ranges, yielded by each channel reach for a specific storm event. The mass of sediment

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leaving a channel reach, for a particular particle size range, is equivalent to the mass of sediment for the same particle size range entering the channel reach located immediately downstream. When multiple stream segments are involved (i.e., Walnut Creek and Woman Creek), HEC-6T accounts for channel routing. Data needed to calculate a mass balance for each particle size range for each reach comes from the following sources:

- Sediment mass flowing into the reach from the channel comes from HEC-6T data;
- Sediment input flowing into the reach from a hillslope comes from WEPP data redistributed to the nine HEC-6T particle size-ranges;
- Deposition in the channel reach is calculated by subtracting all of the inputs (HEC-6T channel sediments and WEPP hillslope material) from the reach output (HEC-6T data, described in Step 4 below); and
- Sediment mass flowing out of the reach from the channel comes from HEC-6T data.

The sum of all mass inputs (channel sediment inflow plus hillslope material inflows into the reach) minus all mass outputs (deposition in the channel reach plus channel sediment outflow) is equal to zero for each channel reach. This process is repeated for every channel reach of every stream segment to produce a detailed accounting of sediment mass transport, by particle size, for the entire drainage (see Figure B-11).

B.8.2.2 Calculate Actinide Loads from Hillslopes

For each hillslope input to the channel, a calculation is made to estimate the amount of Pu-239/240 and Am-241 activity (in units of pCi) transported into the channel reach as a result of erosion processes. Pu-239/240 and Am-241 activity loads are quantified for each of the nine particle size ranges discharged from each hillslope. The following description outlines the algorithm for quantifying hillslope discharges of Pu-239/240. Calculations for hillslope Am-241 discharges follow the same process but are unique based on actinide-specific variables described below:

- The mass of sediment for each particle size range discharged at the bottom of the hillslope (from WEPP data) is multiplied by the "bulk" Pu-239/240 activity per unit mass of mixed-particle size material yielded at the bottom of that hillslope (calculated in the GIS model described in Section B.8.1). The result, pCi of Pu-239/240 transported by a specific particle size-range from a hillslope into the channel, does not, however, account for the unequal distribution of Pu-239/240 among equal masses of different particle size ranges; and

- To adjust for the "affinity" that Pu-239/240 has for one particle size-range versus another, "enrichment factors" were calculated, as described in Section B.8.1, that adjust the proportioning of a given "bulk" soil activity among the various particle sizes. An enrichment factor greater than one indicates that a unit mass of that particular particle size has a Pu-239/240 concentration (activity per unit mass) greater than that of the "bulk" (mixed-size) surface soil. An enrichment factor less than one indicates the specific particle size has an actinide concentration that is less than that of the "bulk" surface soil.

Hillslope yields of Pu-239/240 for each particle size (described in the first point above) were multiplied by the corresponding particle size-specific Pu-239/240 enrichment factor. This calculation, repeated for each particle size range for every hillslope, represents the "enrichment-adjusted" total amount of Pu-239/240 (in units of pCi) transported from a particular hillslope into the channel. As noted earlier, Am-241 calculations were performed in the same manner but using Am-241 "bulk" soil activity and Am-241 particle-size-specific "enrichment factors" instead of those used for Pu-239/240.

B.8.2.3 Calculate Actinide Inputs and Outputs by Reach

Similar to the sediment mass loading calculations described in Section B.8.2.1, actinide inputs and outputs are calculated for every particle size for every reach. The following description outlines the algorithm for quantifying Pu-239/240 inputs and outputs for a particular channel reach. Calculations for Am-241 follow the same process but are unique based on actinide-specific variables described below:

1. The amount of Pu-239/240 associated with a specific particle size range flowing into the reach from the channel is equal to the output from the channel reach located directly upstream.

   In those cases where the channel reach is the uppermost in the drainage (i.e., when a reach upstream does not exist), then a special calculation is performed. The Pu-239/240 input (in units of pCi) is calculated by multiplying the sediment load input from the baseflow (from HEC-6T data) by the Pu-239/240 activity per unit mass of the baseflow sediment (derived from either monitoring data or from the Pu-239/240

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activity per unit mass of the nearest hillslope). This value is multiplied by the Pu-239/240 "enrichment factor" for that particle size-range to compute the "enrichment-adjusted" total amount of Pu-239/240 transported into the reach as a result of baseflow.

2. Pu-239/240 inflow to a reach associated with each particle size range from a specific hillslope is calculated as described in Section B.8.2.2.

3. Pu-239/240 deposited in the reach is calculated by multiplying the mass of sediment deposited in the reach (Section B.8.2.1) by the Pu-239/240 activity per unit mass of all the input material (sediments plus hillslope discharges) for that reach. This calculation is based on the assumption that the material flowing into the reach from sediments and hillslope discharges is completely mixed.

4. The amount of Pu-239/240 (in units of pCi) flowing out of the reach is calculated by adding the Pu-239/240 inputs from sediments (refer to point 1) and hillslopes (point 2) and subtracting the amount of Pu-239/240 deposited in the reach (point 3). The estimated total Pu-239/240 flowing out of the reach is used as Pu-239/240 input for the next reach downstream (see Figure B-12).

Again, Am-241 calculations were performed in the same manner but using Am-241 "bulk" soil activity and Am-241 particle-size-specific "enrichment factors" instead of those used for Pu-239/240.

B.8.2.4 Calculate Water Volume Inputs and Outputs by Reach

The HEC-6T output provides the predicted volume of water yielded from each channel reach for a specific storm event. These flow data are converted to the same format as the actinide loading values, described in Section B.8.2.2 above, and used to compute the actinide concentrations in water for each channel reach as described below.

B.8.2.5 Calculate Surface Water Actinide Concentration by Reach

After calculating the actinide loading quantities (Section B.8.2.3) and the water volume inputs (Section B.8.2.4) for each reach, the surface water Pu-239/240 concentration is calculated by dividing the cumulative Pu-239/240 load (in units of pCi) by the cumulative water volume discharged (in units of liters [L]) to get the resulting Pu-239/240 concentration (in units of pCi/L). This calculation is repeated for every reach in the channel. Surface water Am-241 concentrations are calculated in the same way, except that reach-by-reach estimated Am-241 loads are used in place of Pu-239/240.

B.9 Modeling Impacts of Hillslope Remediation on Actinides in Surface Water

To support modeling a range of scenarios involving remediation of hillslopes and the resulting impacts on surface water quality, a module was developed in Microsoft® Excel that links to the surface water actinide concentration model (described in Section B.8 above) for the SID drainage basin. This module allows for rapid evaluation of the effects on surface water quality caused by changes in actinide levels in the soil in the SID drainage basin. The following description involves Pu-239/240, but the module is programmed to also allow similar evaluations of Am-241 levels in the SID.

The soil actinide concentration adjustment model uses, for existing conditions, the average soil activity levels for each one percent interval of each OFE of each SID hillslope as generated by the GIS model (described in Section B.7). The algorithm used to compute the "bulk" activity of soil discharged at the bottom of a hillslope (composed of mixed particle sizes) is also the same as that described in Section B.7.

Functions in the soil actinide concentration adjustment model allow the user to specify the maximum allowable Pu-239/240 soil activity level (in units of pCi/g) for any of the one percent intervals within any OFE in the SID basin. Any intervals that are equal to or exceed the specified Pu-239/240 level are automatically changed or remediated to a new Pu-239/240 soil activity level specified by the user.

Output from the soil actinide concentration adjustment model is used as the new hillslope Pu-239/240 soil activity input in the surface-water actinide concentration model for the SID (Section B.8.2.2). Using the soil actinide concentration adjustment model and the surface-water actinide concentration model together, multiple soil remediation scenarios can be quickly evaluated to assess the relative changes in Pu-239/240 concentrations in SID surface water.

B.10 Particle Size Distribution of Actinides

Estimating the particle size distribution of the sediment leaving the hillslope profiles is extremely important for realistic estimation of the actinide content of the sediment for actinide transport calculations. Lane and Hakonson (1982) showed that knowing the distribution of Pu-

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239/240 on sediment particle size ranges was critical for estimating Pu-239/240 yields in Montandad Canyon at Los Alamos National Laboratory.

WEPP estimates the particle size distribution of the sediment particles leaving the hillslope profiles. The sediment size distribution includes sand-, silt-, and clay-sized particles, which WEPP designates as particles with mean spherical diameters less than 200, 10, and 2 microns, respectively. WEPP also calculates two aggregate particle size ranges, which varied between hillslopes but tended to be about 540 microns (sand-sized) and about 30 microns (silt-sized). WEPP estimates the percentage of particles in each size fraction. The WEPP-estimated particle-size distributions of sediment leaving each hillslope in each watershed are included in Appendix D.

The proportion of sand, silt, and clay particles in the sediment yields from each Site watershed was affected by the amount of disturbed area in the watersheds (e.g., roads). WEPP estimated the particle-size distribution, on a watershed basis, to be about 75 percent sand, about 20 percent silt, and 5 percent clay. Specific gravity of the particles is also predicted by WEPP. The sand-sized aggregates have a lower specific gravity than pure sand (e.g., 2.65 grams per cubic meter [g/cm^3]). This is due to the sand-sized aggregate particles, which contain organic matter and pore spaces (spaces between particles) that lowers the specific gravity of these particles. This makes the aggregates more prone to transport than primary sand particles.

The measured particle-size distributions for "bulk" soils at the Site indicate that about 95 percent of the water-stable aggregates are sand-sized (by mass), 3 percent are silt-sized, and less than 2 percent are clay-sized particles. Measurements of Site soil water-stable aggregate and suspended sediment particle-size distributions were provided by CSM (Ranville and Honeyman, 1998).

The measured water-stable aggregate size distributions for Site soils and bed sediments are shown in Figure B-13. The data for these soil and sediment samples were collected in 1998 to determine the distribution of Pu-239/240 and Am-241 on water-stable soil aggregates and particles of different sizes (Table B-6). The data show that more than 90 percent of the Pu-239/240 and Am-241 are contained in the sand- and silt-sized particles (i.e., larger than 10 microns).

Runoff samples from the 1999 rain simulation experiments at the Hope Ranch (see Appendix A) were collected for determination of particle-size distribution and organic carbon content at CSM. Samples were collected from paired natural and burned rangeland plots for wet and very wet rainfall simulation runs. The preliminary data for these samples is shown in Table B-6. The data indicate that there are mostly fine silt and clay particles in the sediment from the rain simulation experiments.

WEPP predicts the particle-size distribution of erosion-derived sediments from most site soils to contain about 65 percent sand-sized particles. This appears to be an overestimation when compared to the rain simulation data. However, a majority of the Pu-239/240 and Am-241 is associated with particles larger than 10 microns, so overestimation of the percentage of sand-sized particles in the runoff provides a conservative estimate (i.e., higher than actually expected) of Pu-239/240 and Am-241 transport for remediation and management.

The results in Table B-7 indicate that burning does not change the particle-size distribution of the sediment. However, more sediment was observed leaving the burned rainfall simulation plots than the natural plots, as shown by the total suspended solids values. Also, the burned plot runoff had much more dissolved organic carbon than the natural plots. WEPP simulation of runoff and erosion for burned rangeland areas are planned for fiscal year (FY 00).

B.11 References

All references are located in Section 12 of the main report.

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Table B-6. Americium and Plutonium Particle-Size Distribution Analyses for Site Soils and Sediments

(Data provided by CSM, 1998)

Location	*Am-241 Data*					*Pu-239,240 Data*				
		Particle Size Fraction (Microns)			BULK		Particle Size Fraction (Microns)			BULK
		<2	2>10	10>200	SAMPLE		<2 um	2>10	10>200	SAMPLE
15697	Gram Fraction	0.039	0.108	0.715	1	Gram Fraction	0.039	0.108	0.715	1
	Am pCi	0.00244	0.00977	0.0409695	0.058	Pu pCi	0.000885	0	0.0268125	0.022
	% of Total Activity	4%	17%	71%		% of Total Activity	4%	0%	122%	
16297	Gram Fraction	0.011	0.027	0.596	1	Gram Fraction	0.011	0.027	0.596	1
	Am pCi	0.0037	0.00761	0.0482164	0.043	Pu pCi	0.006149	0.0169	0.1043	0.043
	% of Total Activity	9%	18%	112%		% of Total Activity	14%	39%	243%	
16797	Gram Fraction	0.028	0.05	0.572	1	Gram Fraction	0.028	0.05	0.572	1
	Am pCi	0.00554	0.012	0.141284	0.049	Pu pCi	0.010024	0.0146	0.128128	2.32
	% of Total Activity	11%	24%	288%		% of Total Activity	0%	1%	6%	
SSSE00498	Gram Fraction	0.007	0.016	0.343	1	Gram Fraction	0.007	0.016	0.343	1
	Am pCi	0.00291	0.00637	0.089866	0.254	Pu pCi	0.006328	0.0222	0.36358	1.1
	% of Total Activity	1%	3%	35%		% of Total Activity	1%	2%	33%	
SSSE00598	Gram Fraction	0.018	0.01	0.518	1	Gram Fraction	0.018	0.01	0.518	1
	Am pCi	0.00531	0.00235	0.063196	0.0715	Pu pCi	0.01836	0.006	0.309246	0.465
	% of Total Activity	7%	3%	88%		% of Total Activity	4%	1%	67%	
SSSE00698	Gram Fraction	0.01	0.029	0.444	1	Gram Fraction	0.01	0.029	0.444	1
	Am pCi	0.00209	0.0065	0.04884	0.0988	Pu pCi	0.00984	0.0279	0.272172	0.144
	% of Total Activity	2%	7%	49%		% of Total Activity	7%	19%	189%	
SSSE00798	Gram Fraction	0.011	0.023	0.424	1	Gram Fraction	0.011	0.023	0.424	1
	Am pCi	0.00161	0.00334	0.052152	0.038	Pu pCi	0.005137	0.0169	0.124656	0.205
	% of Total Activity	4%	9%	137%		% of Total Activity	3%	8%	61%	
SSSE01198	Gram Fraction	0.029	0.086	0.689	1	Gram Fraction	0.029	0.086	0.689	1
	Am pCi	0.00186	0.00597	0.0333476	0.0448	Pu pCi	0.005771	0.0103	0.0231504	0.247
	% of Total Activity	4%	13%	74%		% of Total Activity	2%	4%	9%	
SSSE01398	Gram Fraction	0.011	0.037	0.44	1	Gram Fraction	0.011	0.037	0.44	1
	Am pCi	0.00175	0.00666	0.035772	0.0342	Pu pCi	0.006677	0.0115	0.07568	0.24
	% of Total Activity	5%	19%	105%		% of Total Activity	3%	5%	32%	
SSSE01498	Gram Fraction	0.013	0.043	0.545	1	Gram Fraction	0.013	0.043	0.545	1
	Am pCi	0.00129	0.00486	0.063765	0.0106	Pu pCi	0.001095	0.0078	0.0508485	0.195
	% of Total Activity	12%	46%	602%		% of Total Activity	1%	4%	26%	
SSSE01498	Gram Fraction	0.02	0.048	0.655	1	Gram Fraction	0.02	0.048	0.655	1
	Am pCi	0.00171	0.00317	0.04847	0.0641	Pu pCi	0.001866	0.0094	0.07074	0.135
	% of Total Activity	3%	5%	76%		% of Total Activity	1%	7%	52%	
SSSE02198	Gram Fraction	0.015	0.019	0.376	1	Gram Fraction	0.015	0.019	0.376	1
	Am pCi	0.00081	0.00146	0.0230864	0.0379	Pu pCi	0.00246	0.0014	0.0247784	0.0698
	% of Total Activity	2%	4%	61%		% of Total Activity	4%	2%	35%	
SSSE05198	Gram Fraction	0.014	0.019	0.593	1	Gram Fraction	0.014	0.019	0.593	1
	Am pCi	0.01249	0.01395	0.340975	0.252	Pu pCi	0.08218	0.1246	3.17848	3.96
	% of Total Activity	5%	6%	135%		% of Total Activity	2%	3%	80%	
SSSE05198	Gram Fraction	0.006	0.017	0.53	1	Gram Fraction	0.006	0.017	0.53	1
	Am pCi	0.03216	0.06732	1.5741	0.252	Pu pCi	0.03216	0.0673	1.5741	2.69
	% of Total Activity	13%	27%	625%		% of Total Activity	1%	3%	59%	
SSSE05298	Gram Fraction	0.02	0.03	0.446	1	Gram Fraction	0.02	0.03	0.446	1
	Am pCi	0.214	0.288	2.60018	6.35	Pu pCi	1.182	1.689	14.718	34.2
	% of Total Activity	3%	5%	41%		% of Total Activity	3%	5%	43%	
SSSE05398	Gram Fraction	0.018	0.025	0.495	1	Gram Fraction	0.018	0.025	0.495	1
	Am pCi	0.6966	1.5475	16.236	20.1	Pu pCi	3.24	9.125	158.895	397
	% of Total Activity	3%	8%	81%		% of Total Activity	1%	2%	40%	
SSSE05498	Gram Fraction	0.022	0.036	0.426	1	Gram Fraction	0.022	0.036	0.426	1
	Am pCi	0.02618	0.04968	0.329298	0.855	Pu pCi	0.1408	0.2981	1.90848	4.77
	% of Total Activity	3%	6%	39%		% of Total Activity	3%	6%	40%	
SSSE05598	Gram Fraction	0.011	0.02	0.436	1	Gram Fraction	0.011	0.02	0.436	1
	Am pCi	0.03927	0.0818	0.8284	1.67	Pu pCi	0.2123	0.394	5.014	8.8
	% of Total Activity	2%	5%	50%		% of Total Activity	2%	4%	57%	
SSSE05698	Gram Fraction	0.017	0.043	0.393	1	Gram Fraction	0.017	0.043	0.393	1
	Am pCi	0.015	0.050	0.393	0.845	Pu pCi	0.06698	0.2937	1.59951	3.25
	% of Total Activity	2%	6%	47%		% of Total Activity	2%	9%	49%	
SSSE05798	Gram Fraction	0.018	0.028	0.490	1	Gram Fraction	0.018	0.028	0.49	1
	Am pCi	0.0252	0.03892	0.4949	0.666	Pu pCi	0.08388	0.2209	2.3667	3.38
	% of Total Activity	4%	6%	74%		% of Total Activity	2%	7%	70%	
SSSE05798	Gram Fraction	0.017	0.028	0.446	1	Gram Fraction	0.017	0.028	0.446	1
	Am pCi	0.01734	0.03696	0.363936	0.658	Pu pCi	0.13872	0.1784	1.84198	3.44
	% of Total Activity	3%	6%	55%		% of Total Activity	4%	5%	54%	

	Am-241					Pu-239/240			
SIZE FRACTION	<2	2>10	10>200	200>2000		<2	2>10	10>200	200>2000
AVG % IN EACH FRACTION	3%	6%	55%	36%		2%	5%	55%	38%
STANDARD DEVIATION	1%	1%	16%			1%	2%	14%	

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Table B- 7. Preliminary Data for Rain Simulation Runoff Samples from Hope Ranch in June 1999

(Soil is similar to Denver-Kutch Midway Clay Loam, the WEPP model sideslope soil)

Plot Type and Simulation Type	Dissolved Organic Carbon (mg C/L)	Total Suspended Solids (mg/L)	Size Fraction (Microns)	Number of Particles (Millions/mL)
Natural / Very Wet	19.5	223	<212	7.6
			<53	8.0
			<25	9.1
Natural / Wet	32.5	162	<212	9.7
			<53	9.9
			<25	10.8
Burn / Very Wet	24.5	716	<212	18.3
			<53	18.9
			<25	20.0
Burn / Wet	42	704	<212	17.4
			<53	18.1
			<25	19.3

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Figure B-1. Flow Chart of Sediment Mass Balance

(Applied to each particle size in each channel reach)

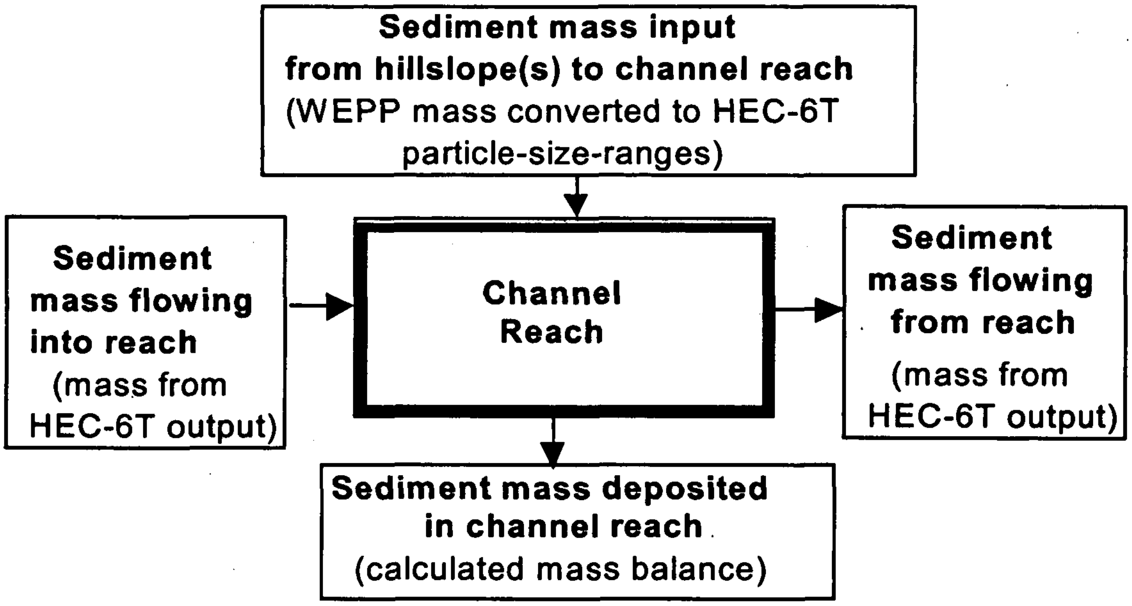


Figure B- 2. Flow Chart of Pu-239/240 Activity Mass Balance

(Applied to each particle size in each channel reach – similar mass balance applied to Am-241)

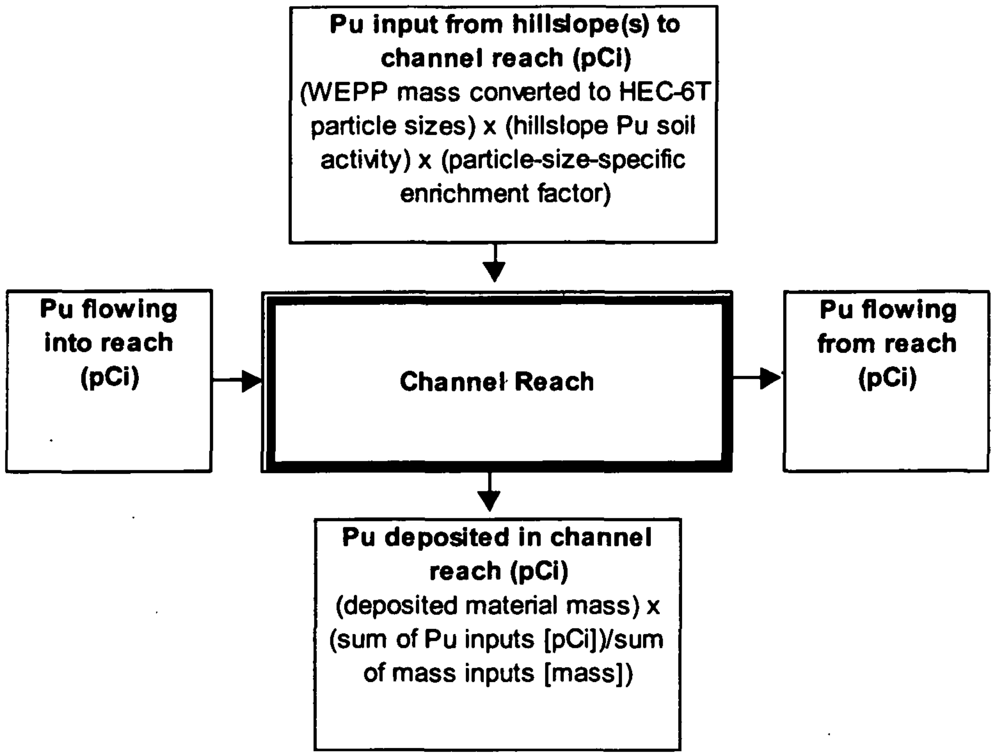


Figure B- 3. Site Area Variogram for Pu-239/240, North-South

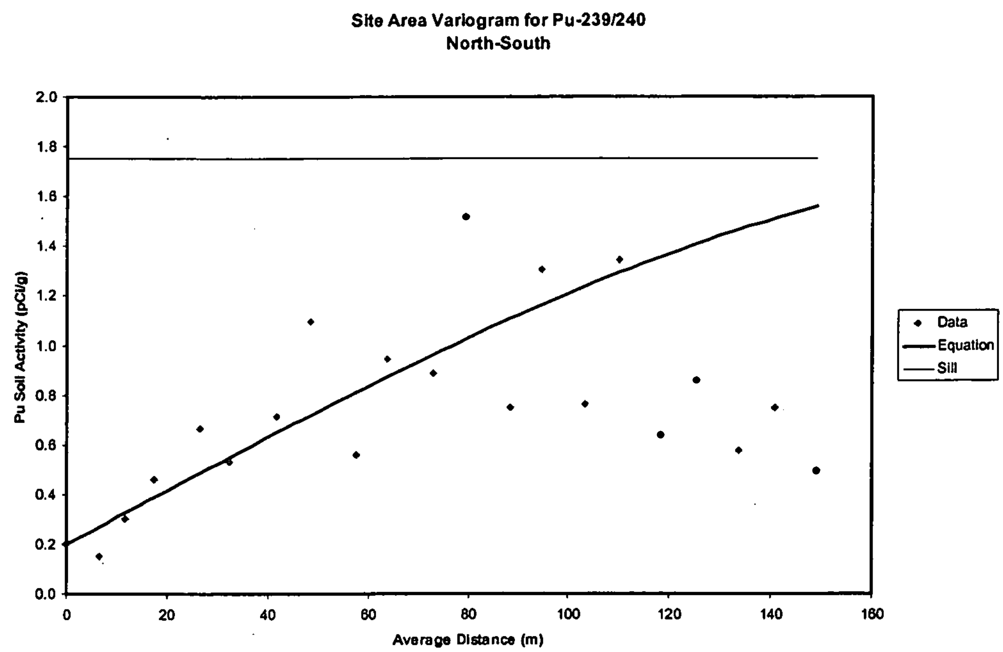


Figure B- 4. Site Area Variogram for Pu-239/240, East-West

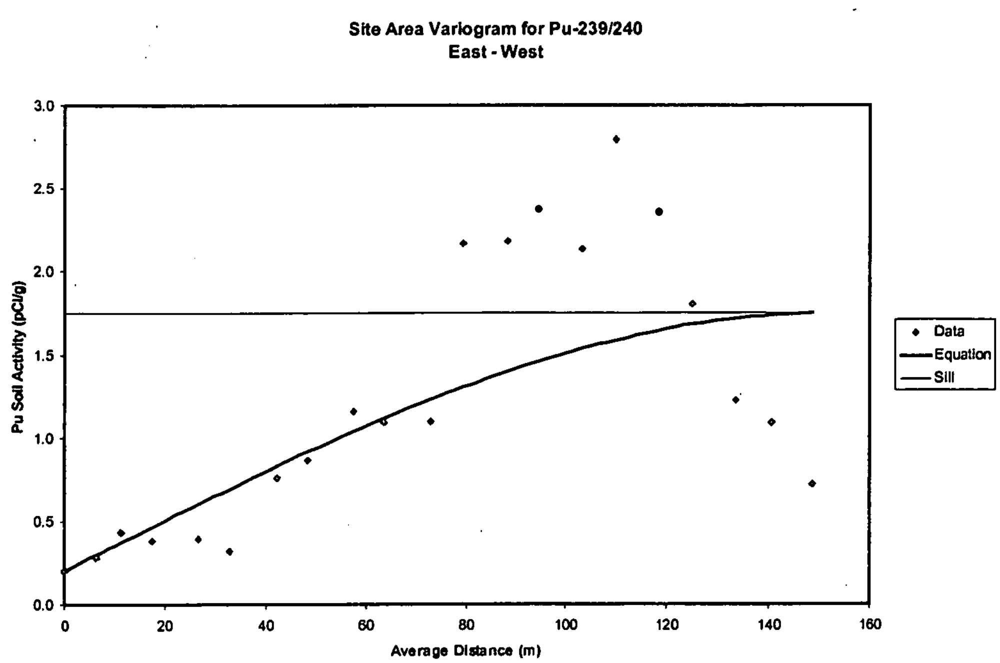


Figure B- 5. Site Area Variogram for Am-241, Northeast-Southwest

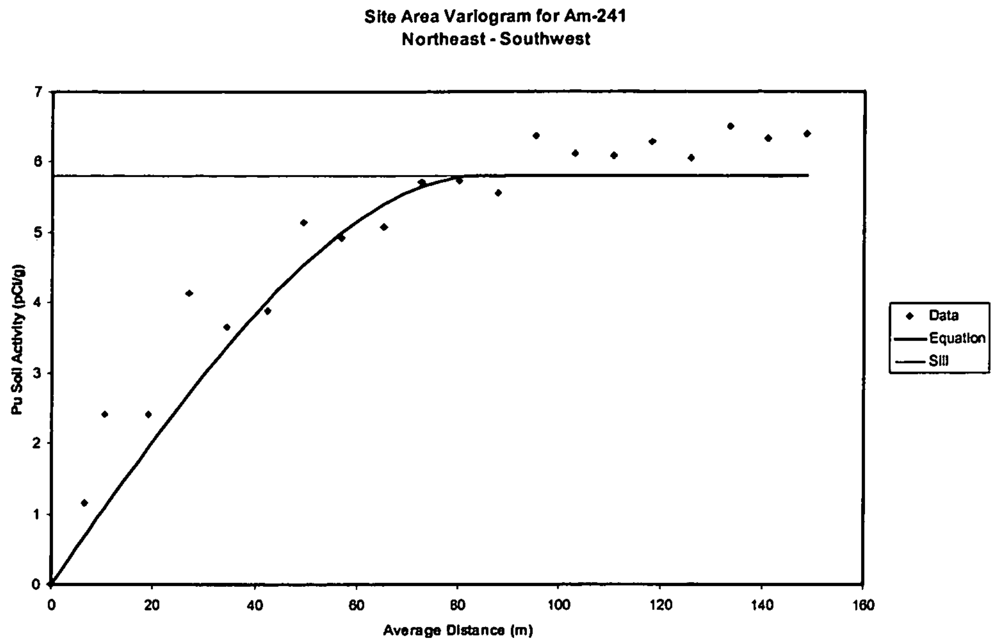


Figure B- 6. Site Area Variogram for Am-241, Northwest-Southeast

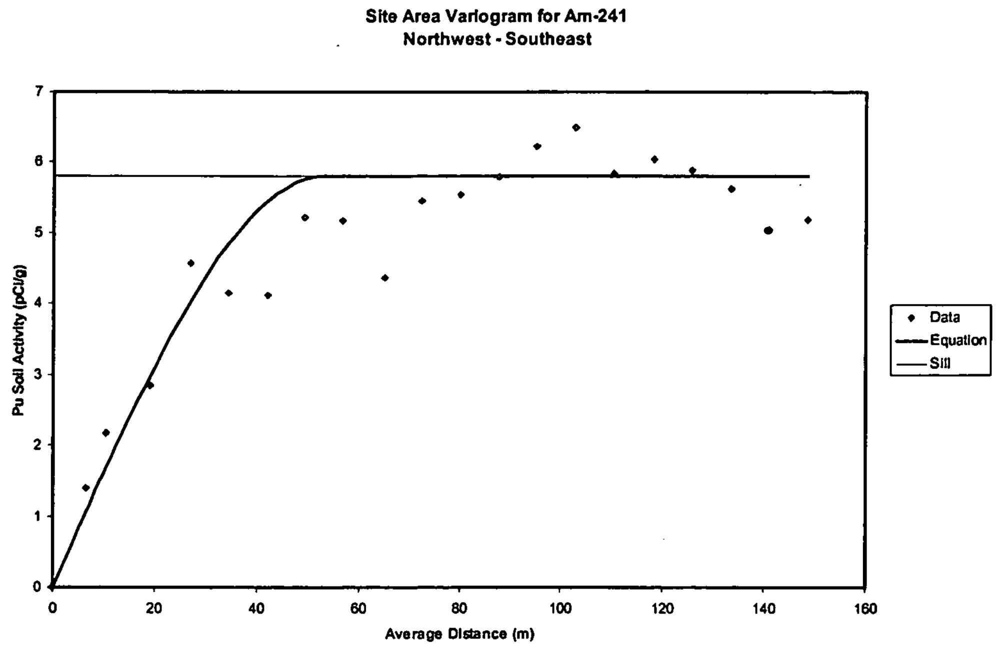


Figure B- 7. Plume Variogram for Pu-239,240, East-West

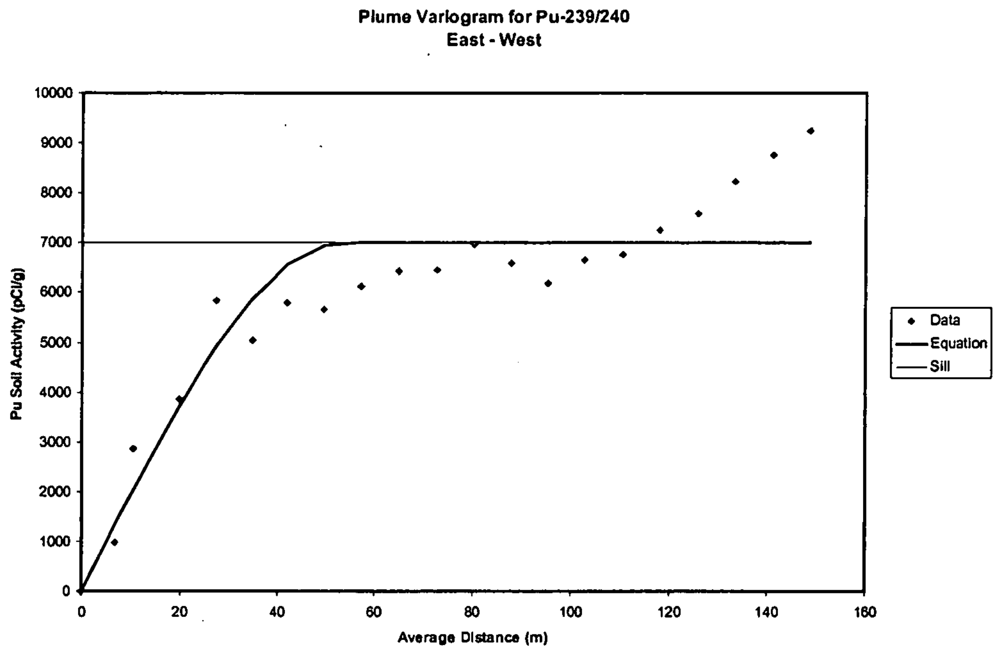


Figure B- 8. Plume Variogram for Pu-239/240, North-South

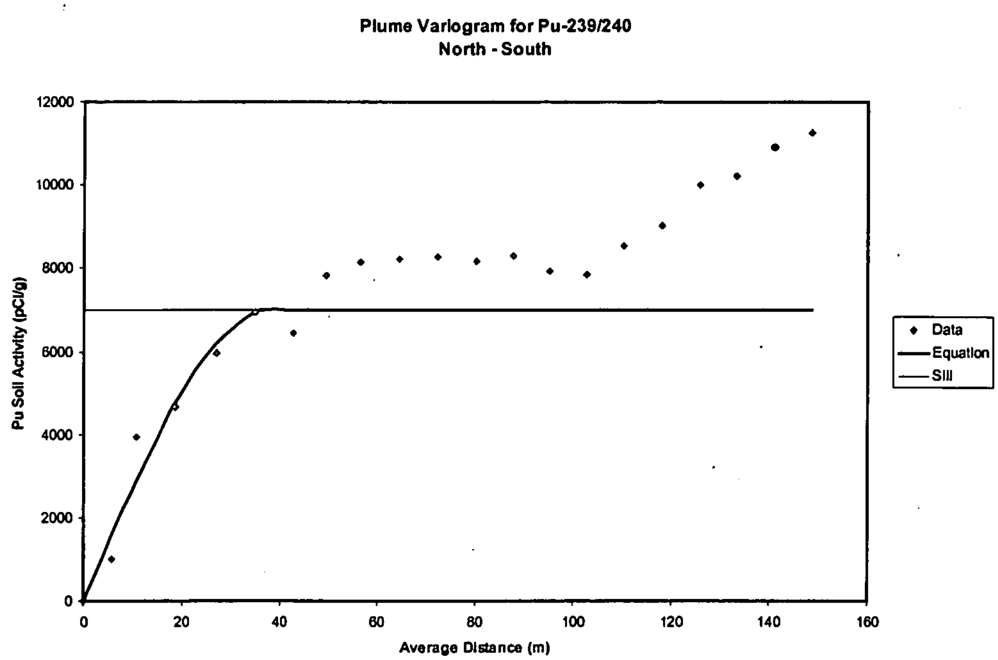


Figure B- 9. Plume Variogram for Am-241, East-West

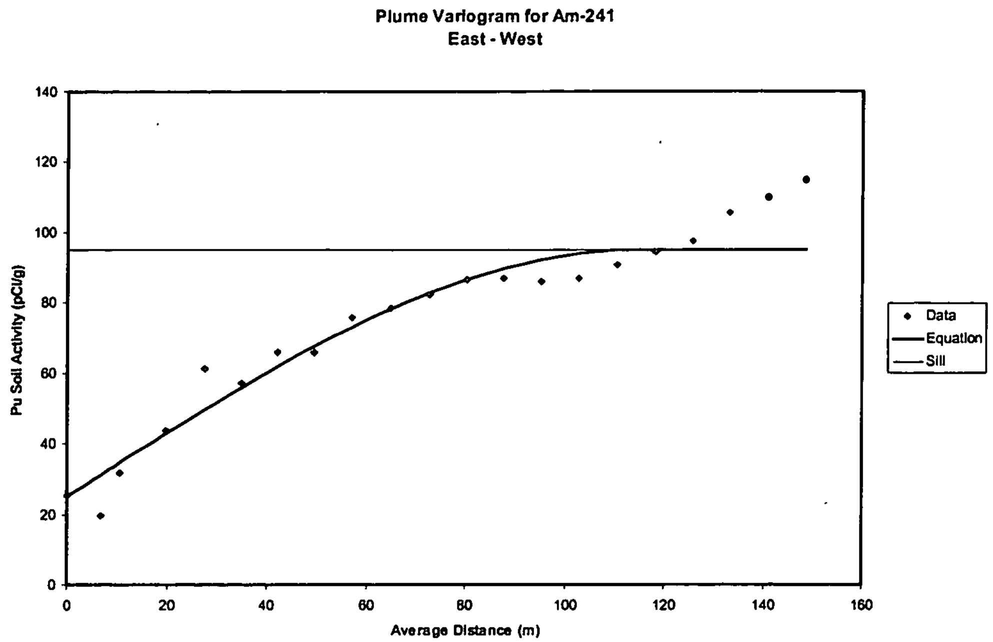


Figure B- 10. Plume Variogram for Am-241, North-South

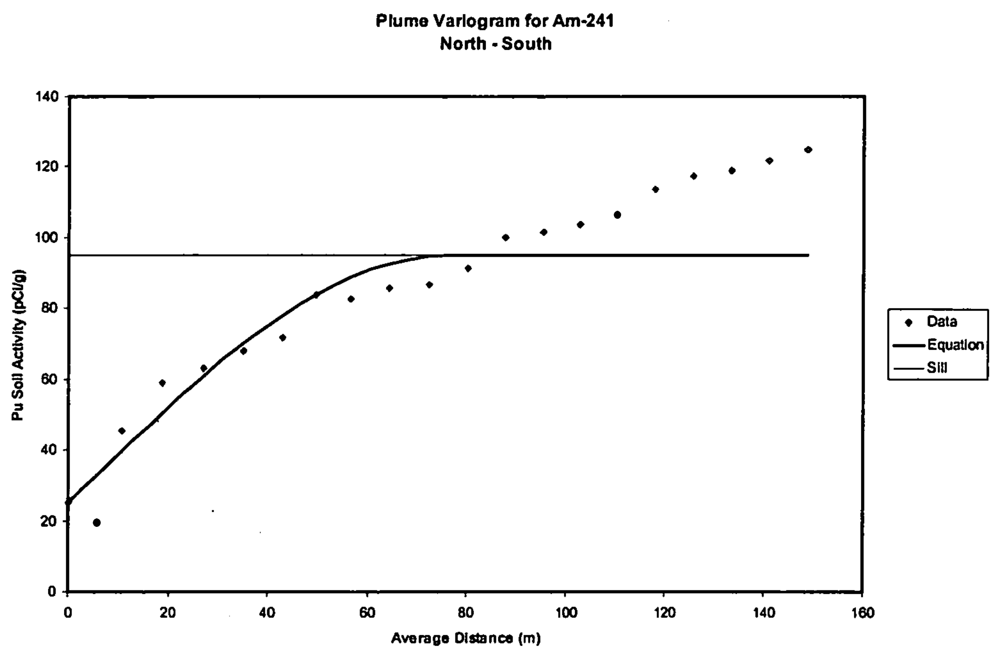
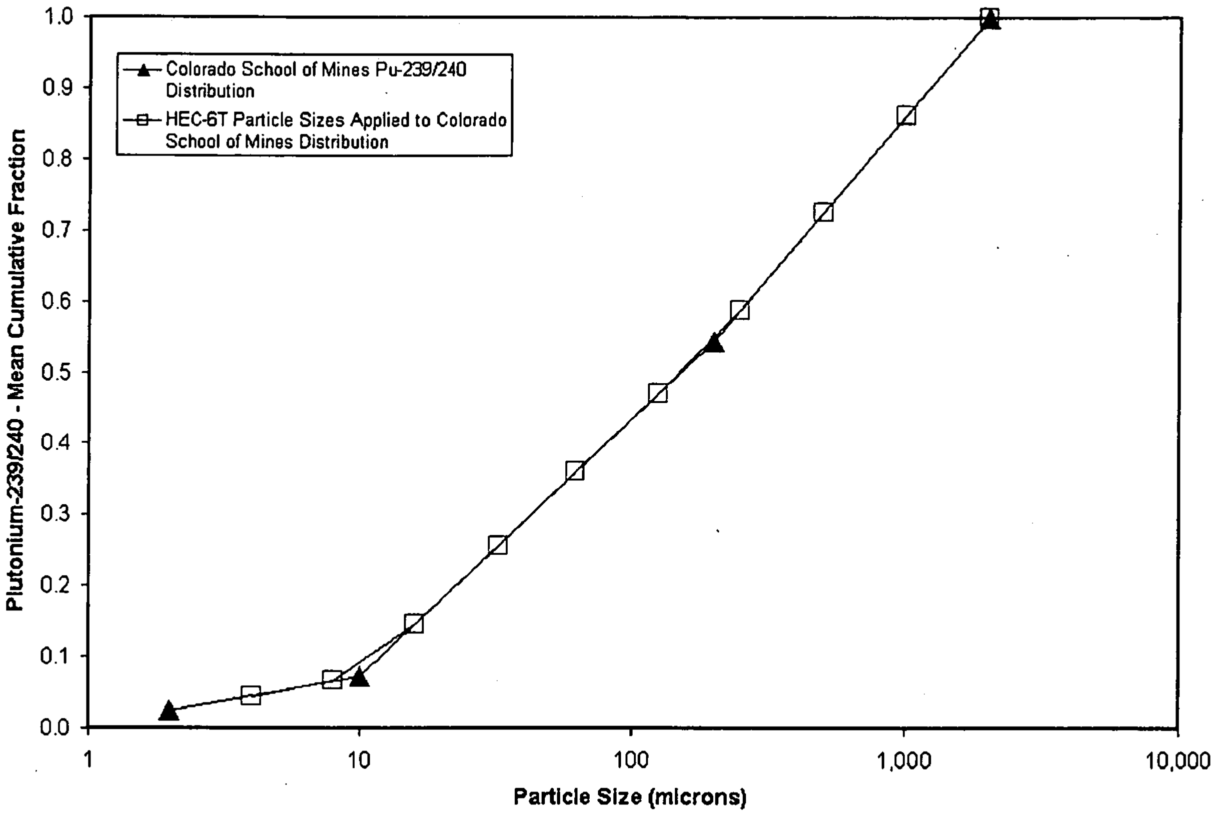


Figure B- 13. Cumulative Distribution of Plutonium-239/240 Among Particle Sizes of All Soil Types (CSM Data Distribution Applied to HEC-6T Particle Sizes)



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C.1 HEC-6T Model Design and Calibration

The Sedimentation in Stream Networks (HEC-6T) model was used to simulate the hydraulic characteristics of the Site stream channels and estimate suspended sediment transport. This section presents the important measured, fixed, and adjusted parameters of the model and discusses sensitivity to Manning's n-values and streambed erosion. Calibration and performance of the model are described in Sections C.2 through C.8.

C.1.1 HEC-6T Model Parameters

C.1.1.1 Measured and Fixed Parameters

HEC-6T uses the cross-sectional and longitudinal geometry of the stream channels and the streambed grain-size gradation to simulate the hydraulic conditions of the stream channels. The grain-size gradation of the streambed sediment and the channel geometry were measured in the field, and the measured data were input into the HEC-6T models. These parameters are fixed and do not change in the model calibration process. Other important parameters and input data that are fixed in the HEC-6T models include the following:

- Sediment particle size distribution of each tributary inflow as determined by the Water Erosion Prediction Project (WEPP) model;
- Specific gravity of each particle size class (i.e., sand, silt, and clay specific gravity) as determined by WEPP;
- The sediment discharge rating curve that correlates stream discharge (cubic feet per second) to sediment discharge (tons/day) for each tributary inflow as determined by WEPP for each hillslope;
- The runoff hydrographs for each tributary inflow; and
- The resistance of the streambed to erosion.

C.1.1.2 Peak Discharge and Sediment Yields

The runoff and sediment yields for each tributary inflow are determined by WEPP. In the HEC-6T model, the runoff and sediment yields of one or more hillslopes constituted a tributary inflow. The runoff from each tributary inflow is introduced to the main channel as a triangular unit hydrograph. The mass of sediment delivered by the tributary inflow is also routed into the channel via a triangular unit hydrograph method. The triangular unit hydrograph method routes the peak discharge from each tributary into the main channel at approximately the same time. Therefore, the method causes peak discharge rates to be larger than expected; consequently, the sediment yields are also larger than would be expected.

C.1.1.3 Design Storms

Six design storms were modeled in WEPP, and the WEPP output was formatted as input to HEC-6T. These design storms are discussed in the main report and in Appendix A. The design storms include an event that is expected to occur once every year (35-mm, 1-year event); an actual 15-year event that occurred on May 17, 1995; and a 100-year event. Current Site monitoring data serve as the best available estimates of sediment and associated actinide transport for baseflow in Site streams. Therefore, modeling the baseflow conditions is unnecessary.

C.1.1.4 Manning's n-Values

The HEC-6T model supports many different sediment transport equations for various applications. For this study, Yang's equation was selected as the most appropriate sediment transport equation (refer to the main report). In Yang's equation, Manning's n-value (the roughness coefficient) is the parameter that has the largest effect on stream velocity and water surface profiles (depth). Manning's n-values were adjusted for five portions of each channel cross-section to simulate channel roughness effects on channel hydraulics and sediment transport.

Initial attempts to model the Site channels with HEC-6T involved breaking each channel cross-section into three "strips:" 1) the bed and banks, 2) the right overbank, and 3) the left overbank (see Figure C-1). The three-strip model resulted in an unrealistic increase sediment transport when Manning's n-value was increased from 0.02 to 0.06, so a 5-strip model was created for each watershed. The 5-strip model breaks the channel cross-sections into five strips: 1) the bed, 2) right bank, 3) the left bank, 4) the right overbank, and 5) the left overbank. Each strip may be assigned a unique Manning's n-value.

Manning's n-value was adjusted to 0.02 to 0.09 for the channel beds, 0.03 to 0.07 for stream banks, and 0.05 to 0.09 for overbank areas. Higher n-values were selected for the banks to simulate vegetation in stream segments that are known deposition areas. Lower n-values were selected for grass-lined and armored channels. Adjustment of the n-values was done to cause the model to predict sediment deposition in the channel reaches where deposition is observed in the field.

C.1.1.5 Streambed Erosion

Streambed erosion was assumed not to occur in the models; thus, the erodible streambed depth was set to zero. The reasons for this practice and an evaluation of model sensitivity to streambed erosion (or channel erosion) are discussed below.

C.1.2 HEC-6T Model Sensitivity to Manning's n-Value and Streambed Erosion

C.1.2.1 Sensitivity to Manning's n-Value

The suspended sediment transport component of the model is sensitive to adjustment of Manning's n-value, which describes the roughness of the channels. For example, channels armored with large cobbles or lined with short grass have a lower Manning's n-value (e.g., 0.02 – 0.03) than rougher channels that contain cattails and brush (e.g., 0.04 – 0.09) (Van Haveran, 1991).

The HEC-6T model was developed for large river systems with relatively low gradients (e.g., slope = 0.1 percent); however, the Site's upland streams are small and relatively steep (e.g., slope = 1 – 6 percent). This property made initial attempts to model the Site streams result in poor simulation of stream hydraulic characteristics. Unrealistically high flow velocities and instability with respect to the relationship between channel roughness and sediment transport were predicted by HEC-6T, especially for the South Interceptor Ditch (SID). Upward adjustment of Manning's n-values should result in slower predicted velocities and increased sediment deposition in the channel, but initially the exact reverse was predicted as shown in the top graph in Figure C-2. This problem was corrected by performing the following:

- Using three cross-sections to describe each riprap (piles of large diameter, angular stones) drop structure in the SID;
- Reducing the slope of the riprap drop structures in the SID channel geometry and decreasing the n-values at the locations of each drop structure to simulate increased velocity occurring at them; and
- Inserting more cross-sections into the channel geometry so that the average maximum distance between cross-sections is six to eight times the channel width. This step helps to control the stability of the model in calculating backwater conditions due to channel roughness.

Two separate HEC-6T models were created for the SID: one with drop structures and one without drop structures. The top graph in Figure C-2 shows that increasing Manning's n-values causes increased sediment deposition in the SID model with no drop structures. This model was considered to predict reasonable flow velocities and hydraulic conditions, which resulted in more reasonable suspended sediment concentrations. Sediment transport increases as Manning's n-value increases for the SID model with drop structures. Although this is counterintuitive, it was determined that results from both models would be averaged for reasons described below.

The SID channel has an overall 2 percent slope, but the drop structures, located throughout the length of the SID, have slopes between about 8 and 20 percent. HEC-6T predicts supercritical flow on these drop structures, which is flow accelerating due to gravity (e.g., waterfall). However, Site personnel who witnessed and photographed the May 17, 1995, flood observed that the water flows through the large pieces of riprap, not over them. Thus, the riprap controls the energy grade of the water surface, which is their purpose. Therefore, eliminating the drop structures in the HEC-6T models is justified by field observations.

Comparison of the SID model results to the Site monitoring data indicated that perhaps too much sediment deposition was being predicted for the 1-year, 35-mm storm event, especially for the model without drop structures. This casts uncertainty on the predictions obtained for the other design storms. Because this uncertainty is coupled with the fact that the HEC-6T application for the SID is complex, it was decided that the results for the two models should be averaged. Therefore, the data used to evaluate model performance for the SID are shown as an average value with error bars that span the range between the maximum and minimum predicted values.

The techniques learned from modeling the SID channel hydraulics were applied to the models for the other Site watersheds. Increasing the number of channel cross-sections for all of the models helped to control flow velocities, which in turn caused appropriate model response in predicted sediment deposition and transport with respect to changes in Manning's n-values.

C.1.2.2 Sensitivity to Streambed Erosion

The sensitivity of the HEC-6T models to streambed erosion was evaluated. For typical day-to-day storm events and baseflow conditions, streambed erosion is undoubtedly the major process for sediment transport in the Site streams because overland flow is rarely observed in the field. Channel erosion accounts for a smaller portion of the total sediment yield when overland flow delivers sediments to the streams. However, the ratio of sediment contribution from overland erosion to stream channel erosion is unknown and difficult to estimate. The channel erosion component of the HEC-6T model is sensitive to adjustment of the following:

- The depth of the erodible bed material;
- Manning's n-value for the channel roughness; and
- The grain size distribution of the bed.

The bed grain-size distribution was determined in the field with manual pebble count measurements shown in Section C-9. The bed gradation was not adjusted in the model. The depths of the erodible bed can be based on field observations and then adjusted to calibrate the model to produce suspended sediment concentrations for comparison with measured data. This has not been done with the Site models for reasons explained below.

The contribution of channel erosion to the simulated suspended sediment yield was found to easily outweigh the contribution from the hillslopes if enough erodible sediment depth was incorporated into the models as shown in Figures C-3 and C-4. Setting the erodible bed depth too high would have masked the estimated sediment yields contributed by the hillslopes. This would have made calculation of average sediment and actinide concentrations far more complex and would have introduced more uncertainty into the model; thus, the erodible bed depth was set to zero.

HEC-6T treats the erodible (mobile) streambed as non-cohesive sand particles lying on the bed, a material easily resuspended in the water column. The Site streambeds are typically either armored with cobbles and gravel in high gradient areas or covered with cohesive clay-sized materials with abundant vegetation (e.g., cattails) in flatter areas.

Table C-1 compares HEC-6T-estimated sediment yields for two erodible bed conditions for the Woman Creek 10-year event model: no channel erosion and 3 mm of erodible streambed.. The 3-mm of erodible streambed depth causes a 365 percent increase in sediment yield for the 1-year event, but only a 16 percent increase for the 100-year event. These data illustrate that the model predicts that a smaller percent contribution of the total yield is due to channel erosion for large storms, which is expected.

The graphs in each of Figures C-3 and C-4 show how sediment yield increases proportionally to the erodible bed depth for the Woman Creek 10-year event model. Figure C-3 shows how simulated total sediment yield is affected by streambed erosion. The data in Figure C-3 are from a model with zero erodible depth in Segments 5 – 8 and 3, 6, and 12 mm of erodible streambed in

Segments 1 – 4. Note that the outlet of Segment 1 is the end of the modeled watershed at Indiana Street. Figure C-3 shows that total sediment yields increase between 1 and 16 percent for erodible bed depths of 3 to 12 mm, respectively. Figure C-4 shows results of assuming erodible depths of 3 to 12 mm for all of the model segments, whereas total sediment yields increased from 5 to 25 percent, respectively, at the outlet of Segment 1. Therefore, HEC-6T predicts significant increases in sediment yield for very small depths of erodible streambed.

Actinides are associated with the streambed sediments (Figures C-5 and C-6); therefore, suspension of bed sediment into the suspended load will increase the actinide concentration in the water column. Based on the sensitivity analysis results and the relatively low activity of the bed sediments compared to soil activity, the increase in predicted actinide concentrations from channel erosion would be small (e.g., about 10 percent). Simulated resuspension of streambed sediment would increase the predicted surface-water actinide concentrations; therefore, including simulated channel erosion in the models would not change the conclusions of the study. The HEC-6T models can be refined to include channel erosion, but linking the channel erosion component to the actinide transport models (refer to Appendix B) was too complex to be completed for this report.

C.2 HEC-6T Calibration

Calibration of the HEC-6T models was conducted via a two-step process. The first step consisted of ensuring that the WEPP and HEC-6T models were properly integrated. In the second step, HEC-6T model results were compared to measured data. These calibration activities are discussed below.

C.2.1 WEPP/HEC-6T Integration

Cumulative HEC-6T tributary (hillslope) runoff was compared to the WEPP runoff, and agreement within 10 percent error was determined to be acceptable. Because the HEC-6T output is not formatted in a way that facilitates straightforward checking of the tributary sediment yields, the tributary sediment yields were checked in a spreadsheet using the same algorithm used by HEC-6T to route the sediment into the channels. Finally, the HEC-6T output was compiled to compare the cumulative WEPP hillslope yields and the HEC-6T sediment yields for each watershed.

C.2.2 Comparison of HEC-6T Results with Measured Data

Site monitoring data from stream gaging stations were used to evaluate how well the HEC-6T model represents Site conditions. The Loading Analysis for the Actinide Migration Studies at Rocky

Flats (RMRS, 1998b) and the Drainage and Flood Control Master Plan (EG&G, 1992b) were also used to calibrate the model. These resources are described in greater detail below.

C.2.2.1 Loading Analysis

The Loading Analysis is a compilation of available surface water discharge, total suspended solids (TSS), and actinide activity data from Site monitoring programs. The report includes computed actinide loads on a storm-specific and annual basis for Site monitoring stations. The Loading Analysis includes estimates of the annual TSS yields measured at Site stream gaging stations in Woman Creek, Walnut Creek, and the SID, and these estimates served as calibration targets for the WEPP and HEC-6T models. Runoff coefficients are also presented for the gaging stations. The runoff coefficient describes the percentage of precipitation that will run off of a drainage basin as surface water (Dunne and Leopold, 1978). The measured runoff coefficients were compared to those simulated by WEPP and HEC-6T.

Data for the Loading Analysis were compiled from the following Site monitoring programs:

- Event-Related Surface Water Monitoring Program, 1991-1994;
- Industrial Area Interim Measure / Interim Remedial Action (IM/IRA) Monitoring Program, 1995-Present;
- Rocky Flats Cleanup Agreement (RFCA) Monitoring Program, 1996-Present; and
- Source Evaluation and Preliminary Mitigation Program, 1997-Present.

For some of the gaging station data in the Loading Analysis, only a few water quality samples were available, which resulted in considerable uncertainty in the sediment yield estimates at those stations. Actinide and TSS loads were computed for each gaging station over the period of record with all available data using Equation 1. In order to put the actinide load and yield estimates into a comprehensible form, radionuclide activities were converted to mass using activity/mass ratios shown in Shleien (1992).

$$\text{Load (mass transport / time)} = K \times Q \times [\text{constituent}] \qquad (1)$$

where:

Load	=	a "mass flow," commonly called "flux" in units of mass per unit time (e.g., micrograms [μg]/year);
K	=	a constant for appropriate unit conversion;
Q	=	stream discharge, in liters (L)/second; and
[constituent]	=	actinide (μg/L) or TSS (milligrams [mg]/L) concentration.

Equation 1 is used to compute storm-specific loads using the average flow (measured during collection of the stormwater sample). The minimum, mean, and maximum storm-specific loads were calculated for each gaging station.

The estimations of TSS and actinide loads at each gaging station were used to compute annual total yield (i.e., total mass) of TSS and actinides transported to each station (see Equation 2). The yields may be compared spatially to locate actinide source and deposition areas.

$$Y = K \times Vw \times [\text{constituent}]Ave \qquad (2)$$

where:

Y	=	Constituent Yield (mass) (e.g., μg);
K	=	Constant for appropriate unit conversion;
Vw	=	Annual total water yield (volume) in liters; and
[constituent]Ave	=	Average annual actinide (μg/L) or TSS (mg/L) concentration.

Discharge and water quality data for the May 17, 1995, flood were included in the Loading Analysis for stations SW027, GS21, GS22, GS24, GS25, GS10, and SW093. The May 17, 1995, event was approximately a 15-year, 24-hour event. The loading estimates from the May 17, 1995, event are considered to be representative of expected actinide transport during floods. The uncertainty of the TSS and actinide analytical data and the error associated with the flow monitoring data are evaluated in the report. A summary of the Loading Analysis results is shown in Table E-5 on the CD-ROM provided with this report.

C.2.2.2 Master Plan

The Drainage and Flood Control Master Plan (Master Plan) presents the results of hydrologic modeling and floodplain delineation using the Colorado Urban Hydrograph Procedure, Stormwater Management Model, the HEC-2 model, and HydroCAD™. The Master Plan also addresses water quality issues with respect to sediment yields in streams, drainage system improvements, water rights, and floodplain delineation. The Master Plan results are used to guide engineering design and maintenance of hydrologic control structures to enhance flood protection of Site infrastructure and downstream structures off-Site. The Master Plan provides runoff yields and peak discharge values for 2-, 10-, 25-, 50-, and 100-year return period design storms with total precipitation durations of 2 and 6 hours. These are high intensity rainfall events.

Two low intensity design storms were modeled in WEPP and HEC-6T for comparison to the monitoring data. This was important for calibration, because the majority of available monitoring data describes typical (1-year) storm events. The 35-mm, 11.5-hour event represents a long-duration, low-intensity, springtime storm that generates a moderate amount of runoff and erosion. Such events commonly occur at the Site every spring. Consequently, this event is considered to represent a one-year event. The May 17, 1995, event was a relatively low-intensity event, with 74.9 mm of precipitation falling in about 11.5 hours.

C.3 Runoff and Sediment Yields – Overall Model Performance

HEC-6T yields and concentrations for the Woman Creek watershed were compared to monitoring data from stations GS01 (Woman Creek at Indiana Street) and GS02 (Mower Ditch at Indiana Street). HEC-6T yields and concentrations for the SID outlet were compared to monitoring data from gaging station SW027. HEC-6T estimated yields and concentrations for Walnut Creek were compared to measurements at station GS03 (Walnut Creek at Indiana Street). The following types of monitoring data were compared to the HEC-6T estimated results:

- Runoff yields;
- Peak discharge;
- Sediment yields; and
- TSS concentrations.

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C.3.1 Overall Performance

The HEC-6T models for each watershed (Mower Ditch, SID, Woman Creek, and Walnut Creek) behave in a consistent and realistic manner with the following characteristics:

- Sediment deposition decreases with increasing discharge (peak flow) (Figure C-7);
- Sediment transport is more efficient in steep channels, and sediment deposition increases in flatter ones (Figures C-8 and C-9);
- The detention ponds act as sediment sinks, with sediment deposition occurring even though the ponds are modeled as full, with flow routed over the emergency spillways (Figures C-8 to C-10);
- Cumulative WEPP sediment yields (in a downstream direction) trend with the HEC-6T routed sediment yields (Figures C-8 and C-9);
- Sediment deposition increases in a west to east (downstream) direction as the natural channel gradients decrease (Figures C-8 to C-10);
- Average suspended sediment concentrations increase with increasing peak discharge (Figure C-11 and C-12);
- Sand and large silt-sized particles are deposited in the models. Clay and small silt-sized particles are efficiently transported through each watershed;
- Simulated sediment yields and concentrations compare favorably with the limited measured data from Site stream gaging stations, the Loading Analysis, and the Drainage and Flood Control Master Plan (Table 10 in report);
- The models produce reasonable estimates of stream-flow and sediment yields (Figures C-13 and C-14); and
- The models produce reasonable estimated stream plutonium (Pu-239/240) and americium (Am-241) concentrations when the HEC-6T results are incorporated into the Pu-239/240 and Am-241 transport models (refer to Figures 45 to 66 in the main report).

Based on comparison of measured and estimated yields for the May 17, 1995 event for the SID (Table C-2), the models generally tend to overestimate runoff yields and peak discharges. The

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May 17, 1995, event is the only extreme flood event that has been measured at the Site, and data for this event are of poor quality, because the event damaged many of the gaging stations in the Site monitoring network. Nonetheless, the models appear to predict runoff, sediment yields, and TSS concentrations to within an order of magnitude of measured or previously modeled values.

C.4 Simulated Sediment Deposition

Comparison of the WEPP-estimated sediment yields to the HEC-6T sediment yields provides a method for estimating the percentage of sediment that is deposited in the stream channels and ponds. The depth of sediment that is deposited in the channels and ponds can be calculated by assuming uniform deposition on a particular width of channel bottom. This section describes sediment core data collected at the Site and presents comparisons of these data to model-predicted deposition for the SID and Site ponds.

C.4.1 Site Sediment Core Data

C.4.1.1. SID

Twelve sediment cores were collected in the SID by the AME project team in 1999. Specifically, three cores were collected at four transects located in deposition areas along the SID channel (see map in Section C-9). The cores were collected with a drive corer manually hammered into the sediment. The cores were extruded from the sleeves, photographed, and described as shown in Section C-9. In all of the SID cores, there was a visible demarcation between dark-colored, organic-rich sediment and underlying clay, which was lighter colored and more fine-grained (see photo in Section C-9). The depth of the dark material was measured and recorded. This depth was used to determine the amount of deposited sediment in the SID. Field bulk density measurements of the top 3-cm of each core were made. Pu-239/240 and Am-241 activities were determined for each transect by sectioning the core from the thalweg (middle) of the channel into thirds and analyzing each third for Pu-239/240 and Am-241 by alpha spectrometry. These data are presented in Section C-9. Table C-3 presents a sediment inventory for the SID channel. Pu-239/240 and Am-241 activities in the Site sediments are shown in Figures C-5 and C-6.

The SID core data are limited in quantity and the cored material is of uncertain origin. No radiometric (e.g., Pb-210) or other measurements were used to determine whether the sediment cores were deposited sediment or original streambed fill material. Design drawings for the Site's engineered channels (Section C-9) show that six inches of topsoil were placed in the SID channel for revegetation of the channel. Therefore, the cores might represent topsoil fill rather than deposited sediment. Furthermore, if channel erosion removed the topsoil from the SID channel and deposited it into Pond C-2, then cores from Pond C-2 might be more representative of SID channel erosion (i.e. transport of the fill material) rather than hillslope soil erosion and transport. Therefore, evaluation of the model performance cannot be based on the sediment core data alone, and such comparisons should be made with caution.

C.4.1.2 Site Detention Ponds

Three to five cores were collected in each detention pond for the Operable Units 5 and 6 Resource Conservation and Recovery Act (RCRA) Facility Investigations. Detention pond bottom sediment coring and associated data collection were done by the same procedure used for the SID coring. The A-series and B-series ponds were cored in five locations: at the deepest parts of the ponds, at the inlets to the ponds, and at three randomly selected locations. The C-series ponds were cored at three locations: at the inlets, at the deepest parts of the ponds, and near the pond outlets. The cores were analyzed for radiochemical and other constituents, but no bulk density measurements were made. Table C-4 shows sediment inventories for Site detention ponds. Pu-239/240 and Am-241 activities in the Site sediments are shown in Figures C-5 and C-6.

The detention pond sediment inventory data should be used with caution for the same reasons described above for the SID data. Additional uncertainty in the usefulness of the pond data stems from changes in the ways the ponds were used in the past. For example, Ponds A-1, A-2, B-1, and B-2 used to be flow-through ponds and contained water from various sources, such as laundry water and wastewater treatment plant effluent (EG&G, 1992). Therefore, the bottom materials in these ponds cannot necessarily be linked to erosion and sediment deposition. Although there is uncertainty in the sediment coring data, the data provide a means for assessing the reasonableness of the model results.

C.4.2 Sediment Balance and Comparison for SID

This section presents the sediment balance prepared for the SID and discusses the comparison with model results. Two different methods were used to compute a sediment balance for the SID watershed to evaluate the WEPP and HEC-6T results.

1. The first method used SID streambed sediment core data and SID watershed surface-water monitoring data to compute the sediment yields to the SID by erosion and Industrial

Area runoff. The yield due to erosion was compared to the erosion rate predicted by WEPP.

2. The second method compared the core data to the HEC-6T-estimated deposition rates for the 20-year life of the SID. The second method used a synthetic 20-year hydrograph comprised of the 1-year, 2-year, 10-year, and May 17, 1995, design storms.

These methods and the results of their application are discussed in greater detail below.

C.4.2.1 Sediment Balance Method 1

The sediment balance uses measured sediment (TSS) yields from gaging stations on channel tributaries to the SID from the Industrial Area as well as the gaging station at the mouth of the SID. Data for the SID cores in Table C-3 are used to complete the sediment balance. This analysis assumes that nearly all of the sediment delivered to the SID has been trapped in the SID channel.

The sediment balance equation for the SID is as follows:

$$dS/dT = \text{Sediment Inflows} - \text{Sediment Outflows} \quad (3)$$

where:

S	=	sediment deposited in the SID channel (kilogram [kg]);
T	=	time (years);
Sediment Inflows	=	Industrial Area inflows measured at gaging stations GS21, GS22, GS24, and GS25 (kg) plus WEPP-estimated hillslope yields; and
Sediment Outflows	=	Sediment yield at gaging station SW027 (kg).

Substituting data from Table C-3 into the equation yields the following expressions:

- dS/dT = 893,239 kg/20 years (yrs) = 44,662 kg/yr = Sediment Inflows – Sediment Outflows;
- Sediment Inflows = Industrial Area Inflows + WEPP-Estimated Hillslope Inflows;
- Sediment Inflows = 6,662 kg/yr + WEPP-Estimated Hillslope Inflows; and
- Sediment Outflows (measured at SW027) = 2,654 kg/yr.

Thus, on an annual average basis, the following balance is obtained:

- 44,662 Kg/yr = 6,662 kg/yr + WEPP-Estimated Hillslope Inflows – 2,654 kg/yr;
- WEPP-Estimated Hillslope Inflows = 44,662 kg/yr – 6,662 kg/yr + 2,654kg/yr = 40,654 kg/yr;
- WEPP-Estimated Hillslope Inflows = 40.654 tons, which is distributed over 74.4 hectares; and
- WEPP-Estimated Hillslope Inflows = 0.546 tons/hectare.

This value (0.546 tons [T]/ha) is almost two times higher than the WEPP-estimated 100-year annual average of 0.384 T/ha. Therefore, this sediment balance method suggests that WEPP appears to be underestimating the erosion by about a factor of two. If the Pond C-2 sediment inventory is added to the balance, WEPP could be shown to underestimate erosion by a larger factor. (Note: This analysis ignores both the application of fill material to the SID channel and channel erosion processes.)

C.4.2.2 Sediment Balance Method 2

A second type of sediment balance was computed for the SID using the HEC-6T-estimated amounts of deposited sediment for each design storm. A 20-year cumulative sediment deposition depth (assuming no channel erosion) was calculated from the WEPP and HEC-6T output in the following manner. A synthetic 20-year hydrograph for the 20-year life of the SID was assumed to include twenty 1-year events; ten 2-year events; two 10-year events; and a single May 17, 1995, event. The amount of WEPP/HEC-6T-estimated sediment deposition for each of these events was summed for each cross section in the SID channel.

The results of this computation and a comparison to the SID sediment core depths are shown in Figure C-15. Figure C-15 shows that some of the core depths are smaller than the deposition predicted by WEPP/HEC-6T, and some are larger. Therefore, this analysis indicates that WEPP might be overestimating erosion and/or HEC-6T might be overestimating sediment deposition. The sediment deposition rates obtained from the cores and the models are similar enough to provide confidence that the model predictions are reasonable.

C.4.3 Comparison of Model Results to Pond Bottom Sediment Inventories

The sediment deposition rates for each pond were calculated using the age of the pond or the most recent date of sediment removal from the pond (refer to Table C-4). These deposition rates were compared to the WEPP/HEC-6T results as an additional assessment of the model predictions. Comparisons were made only for Ponds A-3, B-4, C-1, and C-2 because these ponds are nearly always managed to receive direct runoff. The other ponds are either filled and batch discharged or kept off line for hydrologic management of floods and other potential emergencies.

Results of comparing the WEPP/HEC-6T sediment yields to the pond bottom sediment coring data and to the Loading Analysis are mixed (see Table C-4) as described below:

- Pond A-3: The core data in Table C-4 show that WEPP/HEC-6T might underestimate sediment yield and transport to Pond A-3 by a factor of three or more. However, model-estimated yields to Pond A-3 are a factor of two larger than the Loading Analysis estimates.
- Pond B-4: The models appear to underestimate sediment yield to Pond B-4 by an order of magnitude based on the core data and by a factor of four based on the Loading Analysis results. This is partly explained by the HEC-6T flow routing, which goes through Ponds B-1, B-2, and B-3 prior to entering Pond B-4. On the other hand, Industrial Area runoff is normally routed around these ponds directly into Pond B-4. Also, past industrial discharges to Pond B-4 might account for a significant amount of the Pond B-4 bottom sediment.
- Pond C-1: The models overestimate sediment deposition in Pond C-1 by a factor of two. However, the model-estimated sediment deposition in Pond C-1 matches the Loading Analysis data. Of the four ponds analyzed, Pond C-1 is managed the least by the Site and most closely resembles a water body with natural hydrologic characteristics.
- Pond C-2: Model-estimated sediment yield to Pond C-2 appears to be underestimated by several orders of magnitude based on the core data but by one order of magnitude based on the Loading Analysis results. The models might be underestimating erosion or overestimating sediment deposition in the SID. However, channel erosion of the fill material in the SID channel could also account for the discrepancy.

Overall, the discrepancies between the model-estimated and measured sediment yields and deposition rates might be explained by the following:

- Uncertainties in the sediment coring data as described above;
- Underestimation or overestimation of WEPP erosion rates;
- Ignoring of erosion features and processes such as gullies and channel erosion;
- Underestimation of sediment deposition by HEC-6T;
- HEC-6T model routing of flow through detention ponds and over their emergency spillways; and
- Other unknown sources of error.

The HEC-6T models indicate that detention pond capacities are adequate to contain the 100-year runoff event if the ponds start out empty or nearly empty at the start of the storm and if runoff was allowed to fill the ponds sequentially (see Table C-2). In light of this, the model-estimated sediment and associated actinide transport yields to off-Site areas are conservatively overestimated.

C.5 Runoff and Sediment Yield Results by Selected Stream Reach for Each Design Storm

Figures C-16 through C-38 are provided for detailed analysis of the results obtained for the HEC-6T models. Specifically, these figures present runoff and sediment yield results by watershed and stream reach for each design storm. These results are interpreted and discussed in the main report.

C.6 References

All references are located in Section 12 of the main report.

APPENDIX C TABLES

Table C- 1. Erodible Streambed Analysis for Woman Creek HEC-6T Model, 10-Year Event

[Erodible Streambed Depth = 3 mm; Yield Estimates are for Woman Creek at Indiana street (GS01)]

Storm Event	Sediment Yield with No Erodible Streambed Depth (Metric Tons)	Sediment Yield with3 mm Erodible Streambed Depth (Metric Tons)	Estimated Yield Increase Due to Streambed Erosion (%)
1-Year, 11.5 Hour	0.25	12	365
2-Year, 2-Hour	11	22	103
2-Year, 6-Hour	17	32	83
10-Year, 6-Hour	23	24	5
May 17, 1995	16	21	32
100-Year, 6-Hour	92	107	16

Table C- 2. Comparison of HEC-6T Modeling Results for Site Watersheds

COMPARISON OF HEC6T MODEL RESULTS FOR WOMAN CREEK

EVENT RETURN PERIOD / PROBILITY (YRS) / %	DURATION (HRS)	RAIN (mm)	HEC-6T RUNOFF (mm)	HEC-6T PEAK Q (mm/hr)	MASTER PLAN* RUNOFF (mm)	MASTER PLAN* PEAK Q (mm/hr)	HEC-6T TOTAL QS (Kg)	ESTIMATED DEPOSITION (%)	ESTIMATED Pu CONCENTRATION (pCi/L)	ESTIMATED Am CONCENTRATION (pCi/L)	ESTIMATED TSS CONCENTRATION (mg/L)
2 / 50	2	31.5	1.12	1.64	-	-	1,062	76	1.91	0.137	214
1 / 100	11.5	35	2.51	1.00	-	-	249	91	0.047	0.006	22
2 / 50	6	40.8	2.34	2.21	2.51	0.67	1,745	81	1.06	0.138	168
10 / 10	6	62.3	10.72	7.81	21.71	8.52	20,404	68	1.36	0.188	430
15 / 7	11.5	74.9	16.03	4.45	***42.03***	***3.27***	15,677	68	1.56	0.076	221
100 / 1	6	97.1	32.85	18.64	83.79	36.86	92,196	59	1.882	0.253	633

Master Plan Drainage Area: 554 Ha
WEPP/HEC-6T Drainage Area: 443 Ha

COMPARISON OF HEC6T MODEL RESULTS FOR MOWER DITCH

EVENT RETURN PERIOD / PROBILITY (YRS) / %	DURATION (HRS)	RAIN (mm)	HEC-6T RUNOFF (mm)	HEC-6T PEAK Q (mm/hr)	*MEASURED* RUNOFF (mm)	*MEASURED* PEAK Q (mm/hr)	HEC-6T TOTAL QS (Kg)	ESTIMATED DEPOSITION (%)	ESTIMATED Pu CONCENTRATION (pCi/L)	ESTIMATED Am CONCENTRATION (pCi/L)	ESTIMATED TSS CONCENTRATION (mg/L)
2 / 50	2	31.5	1.10	1.75	-	-	76.2	59	0.52	0.09	97
1 / 100	11.5	35	1.31	0.52	-	-	1.5	84	0	0	2
2 / 50	6	40.8	3.34	2.68	-	-	333	57	1.43	0.263	140
10 / 10	6	62.3	7.08	6.36	-	-	4,904	45	5.6	1.02	972
15 / 7	11.5	74.9	19.05	3.70	***30.13***	***2.52***	5,216	46	3.88	0.66	384
100 / 1	6	97.1	38.62	13.10	-	-	18,952	42	5.89	1.05	689

WEPP/HEC-6T Drainage Area: 71 Ha

*Values from: EG&G, 1992, Rocky Flats Plant Drainage and Flood Control Master Plan (Prepared by Wright Water Engineers, Inc.)
Bold Italics = Estimated from USGS Mean Daily Discharge Data (USGS, 1996)

COMPARISON OF HEC-6T MODEL RESULTS FOR THE SID

EVENT RETURN PERIOD / PROBILITY (YRS) / %	DURATION (HRS)	RAIN (mm)	HEC-6T RUNOFF (mm)	HEC-6T PEAK Q (mm/hr)	MASTER PLAN RUNOFF (mm)	MASTER PLAN PEAK Q (mm/hr)	HEC-6T TOTAL QS (Kg)	ESTIMATED DEPOSITION (%)	ESTIMATED Pu CONCENTRATION (pCi/L)	ESTIMATED Am CONCENTRATION (pCi/L)	ESTIMATED TSS CONCENTRATION (mg/L)
2 / 50	2	31.5	6.3	6.69	-	-	1453	70	12.89	2.03	317
1 / 100	11.5	35	4.8	0.93	-	-	8.42	99	0.159	0.025	2
2 / 50	6	40.8	11.0	8.36	3	0.84	3,552	68	14.0	2.00	440
10 / 10	6	62.3	26.5	19.51	15	9.20	10,901	54	31.9	4.55	562
15 / 7	11.5	74.9	25.3	6.83	***21***	***2.29***	6,871	65	14.87	2.093	370
100 / 1	6	97.1	52.6	43.20	42	30.66	35,237	43	32.8	4.66	915

Bold Italics = SW027 Estimated Data
Master Plan Drainage Area: 63.3 Ha
WEPP/HEC-6T Drainage Area: 74.4 Ha

COMPARISON OF HEC6T MODEL RESULTS FOR WALNUT CREEK

EVENT RETURN PERIOD / PROBILITY (YRS) / %	DURATION (HRS)	RAIN (mm)	HEC-6T RUNOFF (mm)	HEC-6T PEAK Q (mm/hr)	MASTER PLAN* RUNOFF (mm)	MASTER PLAN* PEAK Q (mm/hr)	HEC-6T TOTAL QS (Kg)	ESTIMATED DEPOSITION (%)	ESTIMATED Pu CONCENTRATION (pCi/L)	ESTIMATED Am CONCENTRATION (pCi/L)	ESTIMATED TSS CONCENTRATION (mg/L)
2 / 50	2	31.5	9.90	9.81	-	-	1,720	80	0.013	0.007	40
1 / 100	11.5	35	4.29	2.87	-	-	451	89	0.029	0.007	24
2 / 50	6	40.8	13.57	5.12	5.39	2.23	4,756	77	0.023	0.009	81
10 / 10	6	62.3	30.82	12.60	15.15	8.50	39,982	57	0.086	0.028	301
15 / 7	11.5	74.9	25.30	6.23	15.28	1.28	34,372	61	0.073	0.021	315
100 / 1	6	97.1	65.51	27.83	38.01	24.44	132,007	48	0.126	0.04	467

*Values from: EG&G, 1992, Rocky Flats Plant Drainage and Flood Control Master Plan (Prepared by Wright Water Engineers, Inc.)
Bold Italics = Estimated from USGS Mean Daily Discharge Data (USGS, 1996)
Master Plan Drainage Area: 961 Ha
WEPP/HEC-6T Drainage Area: 431 Ha

Table C- 3. Data for South Interceptor Ditch Sediment Inventory

Estimated Sediment Inventory in SID

SID Channel Segment	Length (m)	Area (m^2)	Cored Sediment Depth (m)	Cored Sediment Depth (mm)	Sediment Volume (m^3)	Measured Bulk Density (Kg/m^3)	Total SID Bed Sediment (Kg)
West End to HS6	467	867	0.076	76.2	66	1,000	66,089
HS6 to HS12	535	1,721	0.097	97.4	168	1,100	184,318
HS12 to riprap drop at HS20	1,331	5,752	0.093	93.1	536	1,200	642,832
HS20 to SW027	109	621	0.182	182	113	1,360	153,766
Totals:	**2,442**	**8,961**			**882**		**893,239**

Estimated Depositon in 20 Year Life of SID

Total Sediment (20 years)		Estimated Deposition Assuming 100% Deposited in SID		
	Kg/20 yrs	Kg/yr	Kg/Ha/yr	mm/yr
Total Sediment (20 years)	893,239	44,662	705	0.054
Toal sediment minus IA inflows	759,999	38,000	600	0.046

Measured Industrial Area Inflow Yields and Outflow at SW027

	Measured Yield (Kg/year)	20 Year Total (Kg)	Industrial Area Total (Kg/yr)	Industrial Area (Kg/20yrs)
Inflows				
GS21	271	5,420		
GS22	5,657	113,140		
GS24	333	6,660		
GS25	401	8,020	**6,662**	**133,240**
Outflow				
SW027	2,654	53,080		

Notes:
HS# = WEPP Hillslope Number in WEPP Model
GS### = Gaging Station Identifier for Industrial Area Runoff
SID is 20 Years Old, Built in 1980
Kg = kilograms
Ha = Hectares (10,000 square meters)
mm = millimeters
IA = Industrial Area

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Table C- 4. Data for Site Detention Ponds

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
DETENTION FACILITY SELECTED SPECIFICATIONS

POND	CREST ELEV. (m)	CREST LENGTH (m)	SPILLWAY ELEV. (m)	SPILLWAY WIDTH (m)	VOLUME (m^3)	Surface Area (m^2)	Sediment Invenories of Selected RFETS Detention Ponds			
							Average Sediment Depth (m)	Sediment (m^3)	Deposition Rate (m^3/Year)	Deposition Rate (Metric Tons/Year)
A-1	1,779	57	1,777	6.10	5,299	4,411	0.44	1,950	97	88
A-2	1,775	78	1,773	6.10	22,712	9,995	0.18	1,828	91	82
A-3	1,768	116	1,766	6.10	46,560	18,655	0.38	7,166	398	358
A-4	1,757	299	1,755	45.7	123,024	35,125	0.14	5,033	419	377
B-1	1,794	61	1,793	4.57	3,785	3,804	0.53	2,006	100	90
B-2	1,791	61	1,790	3.05	5,678	3,966	0.32	1,269	63	57
B-3	1,785	42	1,784	3.05	Flow Through	2,226	0.46	1,031	52	46
B-4	1,780	63	1,778	2.13	Flow Through	1,536	0.61	938	47	42
B-5	1,771	160	1,769	24.4	90,810	24,483	0.17	4,179	348	313
C-1	1,777	78	1,776	9.14	Flow Through	3,334	*0.30*	1,016	23	20
C-2	1,760	360	1,757	76.2	85,549	16,083	*0.19*	3,040	179	161

POND	ESTIMATED DEPOSITION DURATION (Yrs)	APPROXIMATE DRAINAGE AREA (Ha)	SEDIMENT CORING ANNUAL SEDIMENT YIELD TO POND (T/Ha)	LOADING ANALYSIS ANNUAL SEDIMENT YIELD TO POND (T/Ha)	WEPP/HEC6T[1] ANNUAL SEDIMENT YIELD TO POND (T/Ha)
A-3	18	120	2.991	0.378	0.847
B-4	20	86	0.492	0.112	0.038
C-1[2]	45	323	0.063	0.128	0.133
C-2[3]	17	74	2.163	0.084*	0.005

* -Includes WEPP-estimated yields for Hillslopes 29,30, and 49, which drain to Pond C-2.
1 -Estimated using a synthetic hydrograph with WEPP/HEC-6T output for 1-, 2-, 10-, and 15-year events and age of detention pond .
2 -Coring and Loading Analysis Drainage Area = 323 Ha, but WEPP/HEC6T Drainage Area = 203 Ha.
3 -Coring and WEPP/HEC-6T drainage area = 73.4 Ha, but Loading Analysis Drainage Area = 63.3 Ha.

APPENDIX C FIGURES

Figure C- 1. Schematic Representation of HEC-6T Channel Cross Section Structure for 3-Strip and 5-Strip Models

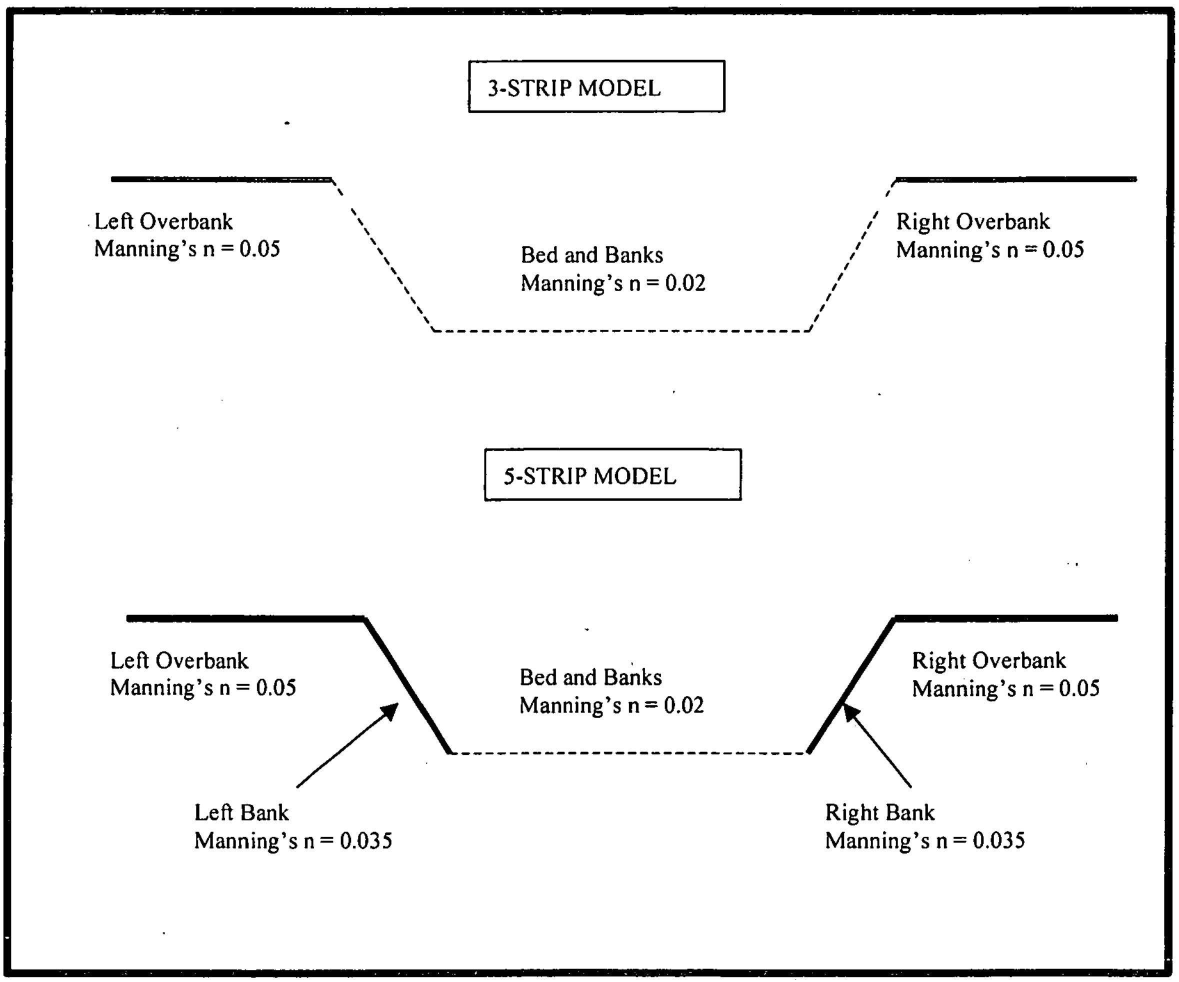
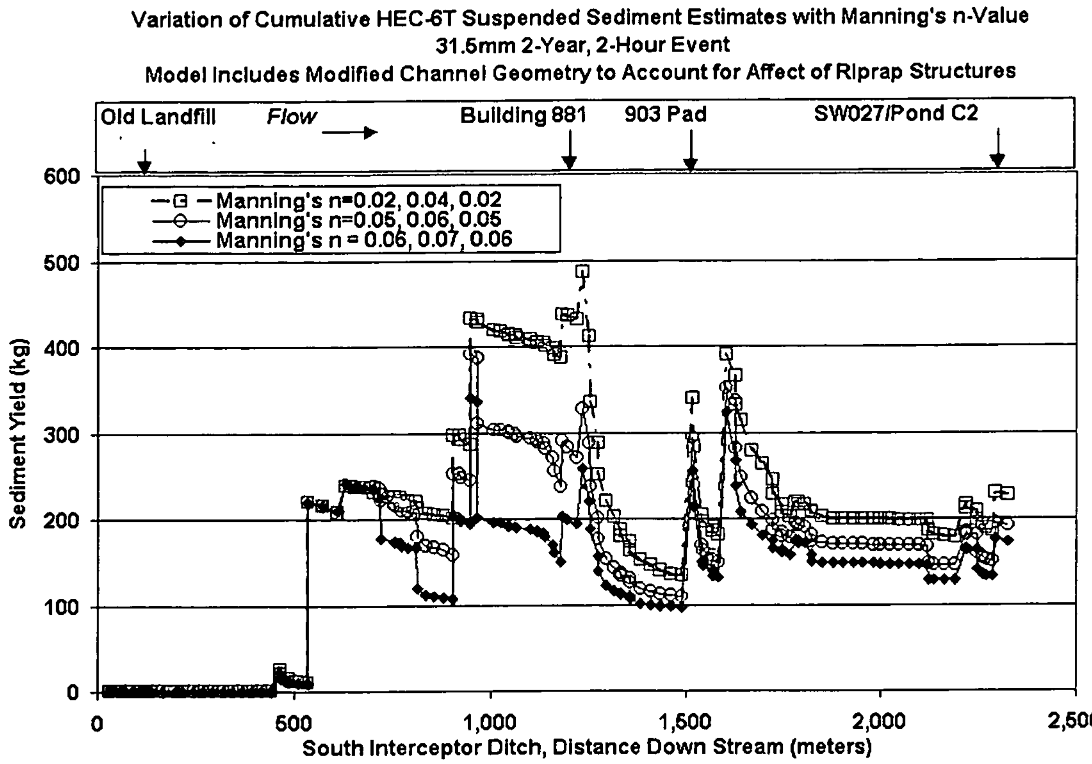


Figure C- 2. Variation of Simulated Sediment Deposition with Manning's Roughness



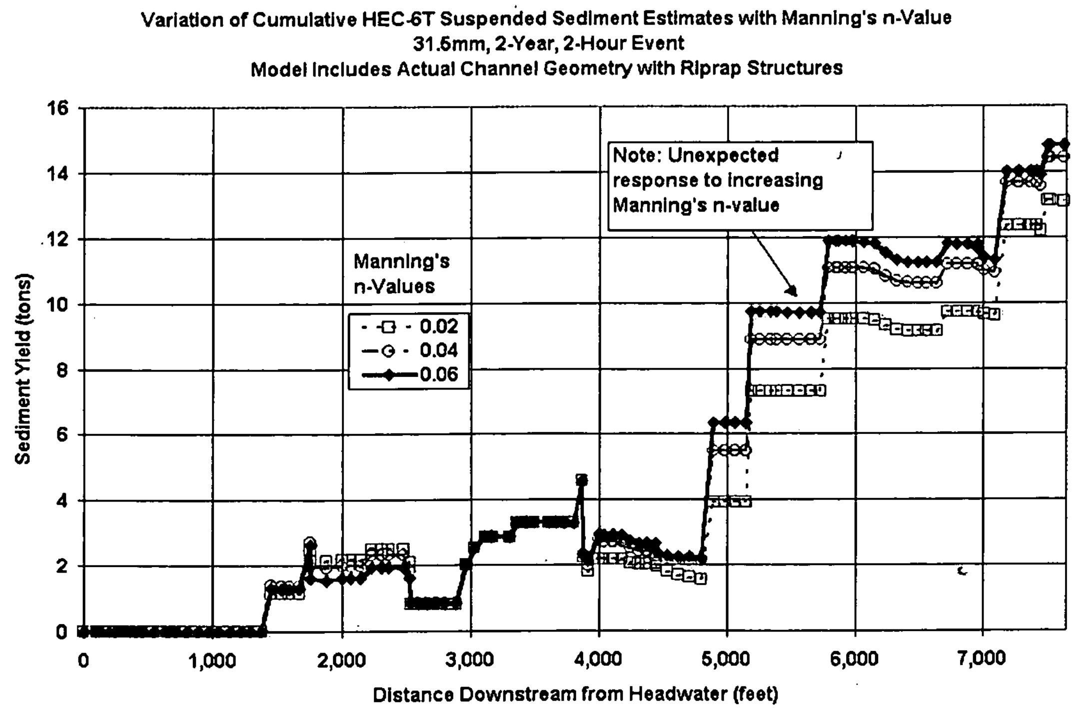


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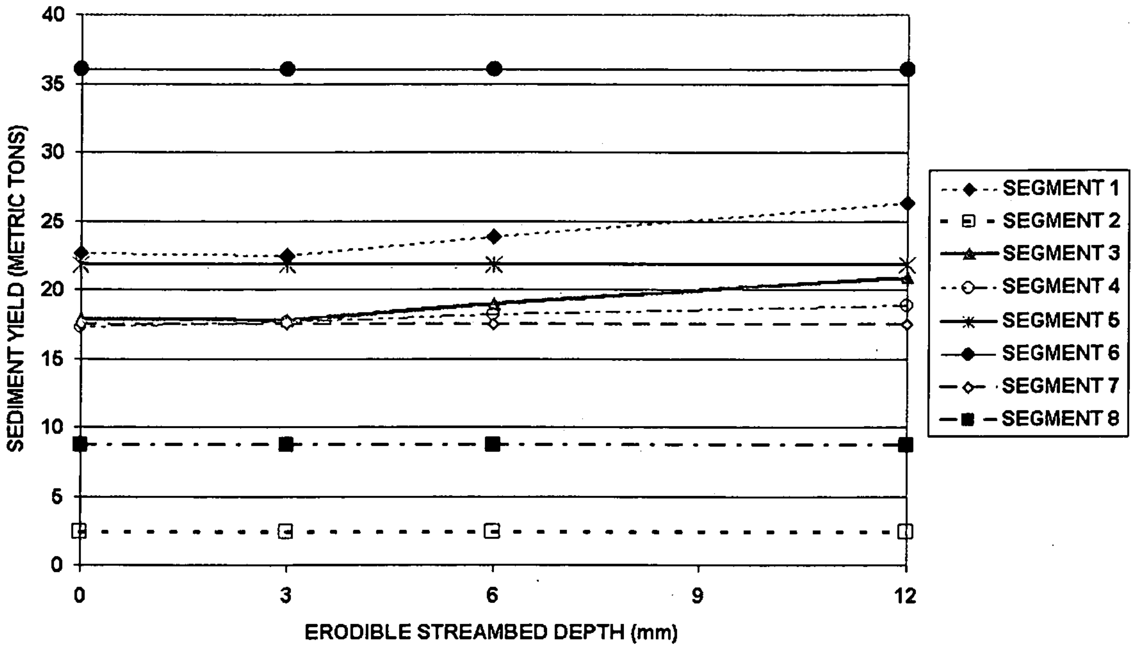
Figure C- 3. Erodible Streambed Depth Analysis Results for Woman Creek HEC-6T Model, 10-Year Event

Comparison of Sediment Yields for Each Stream Segment of the Woman Creek HEC-6T Model for Erodible Streambed Depths of 0, 3, 6, and 12 mm Segments 1 - 4 Erodible, Segments 5 - 8 Non-Erodible



Percent Increase in Sediment Yield for Each Woman Creek HEC-6T Model Segment for 3, 6, and 12 mm Erodible Streambed Depths Segments 1 - 4 Erodible, Segments 5 - 8 Non-Erodible

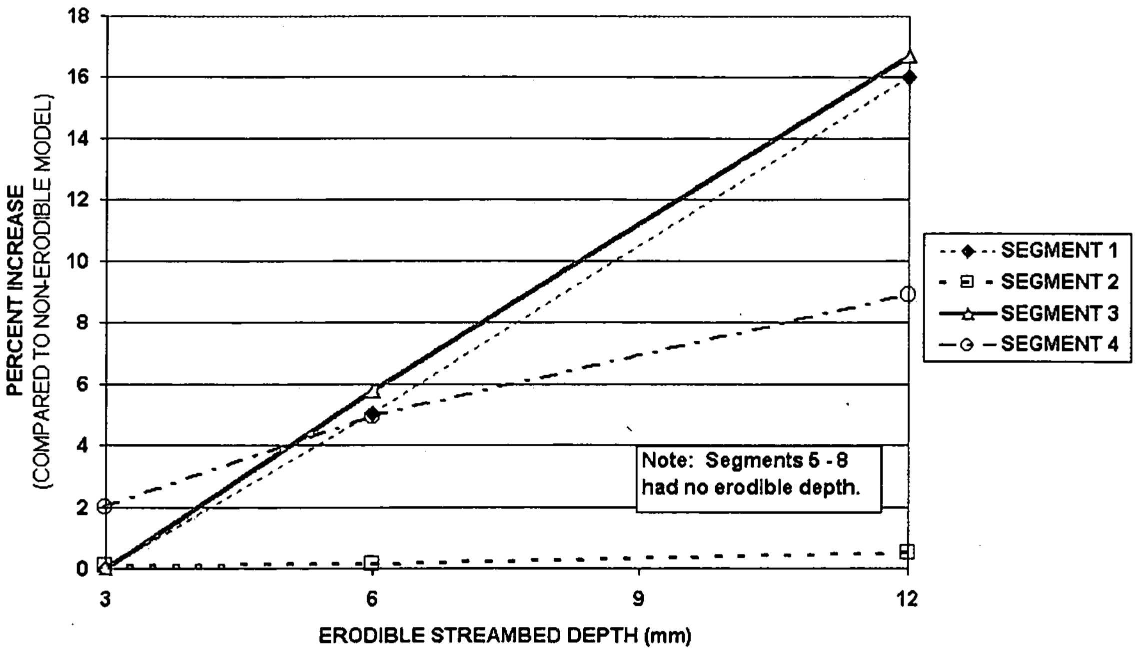
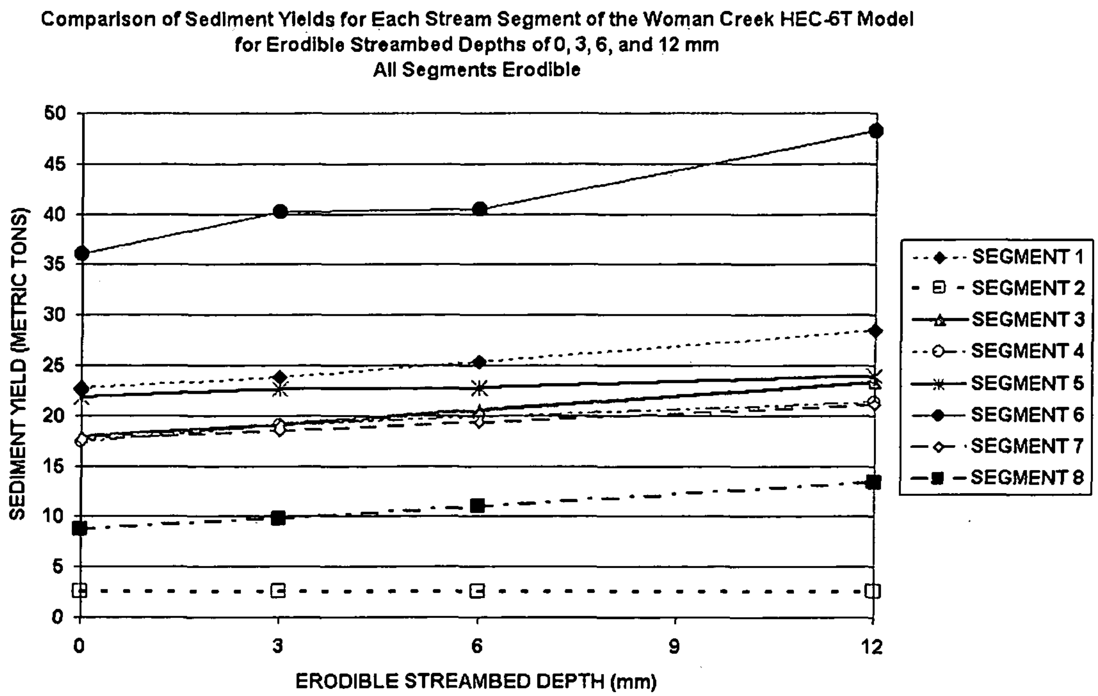


Figure C- 4. Erodible Streambed Depth Analysis Results for Woman Creek HEC-6T Model, 10-Year Event



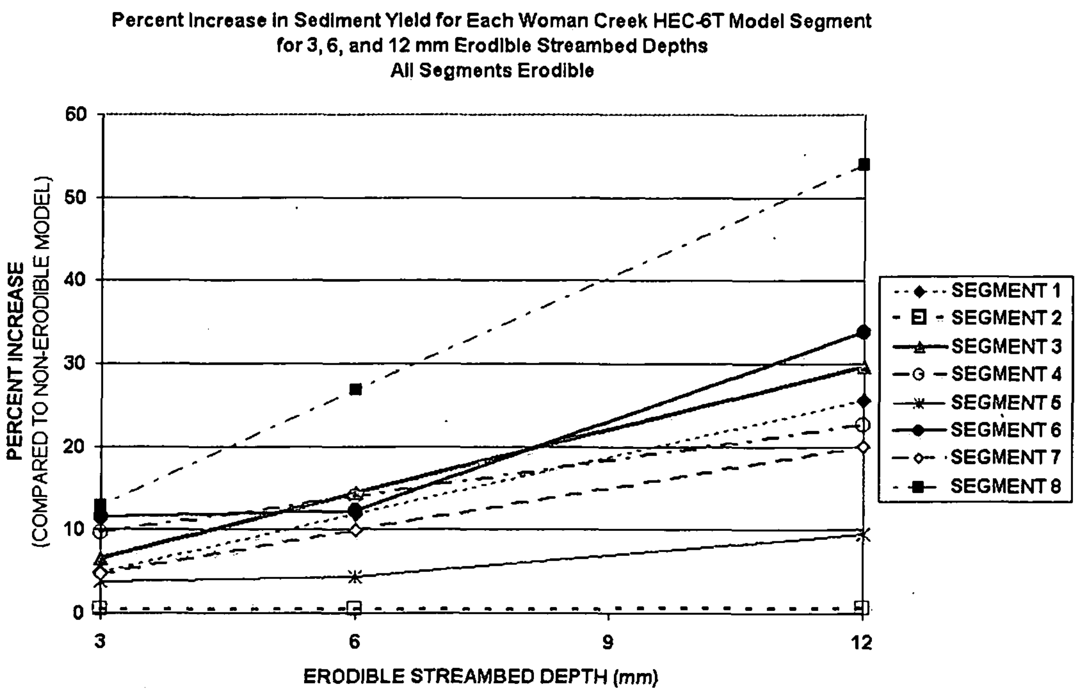


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Figure C- 7. HEC-6T Estimated Sediment Deposition for Site Watersheds

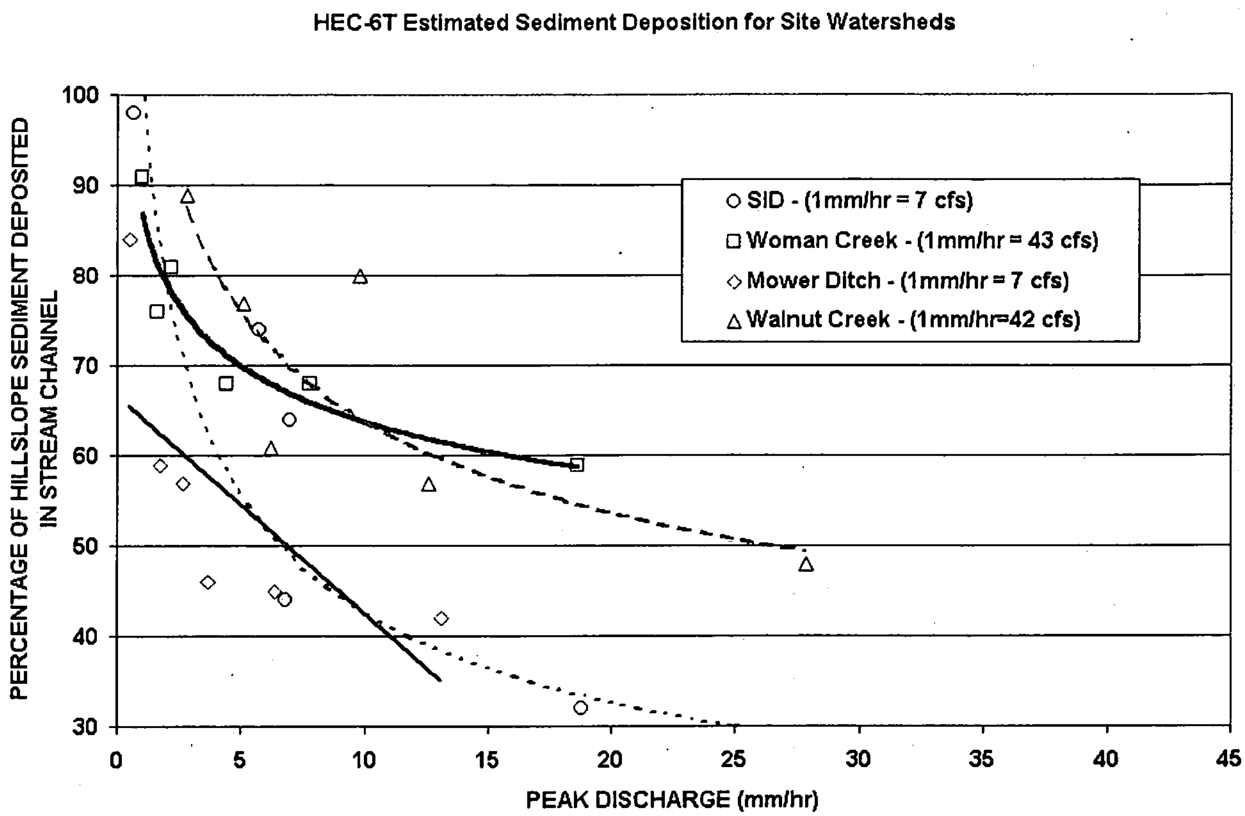

Figure C- 8. WEPP and HEC-6T Results for Woman Creek, 2-Hour, 2-Year Event

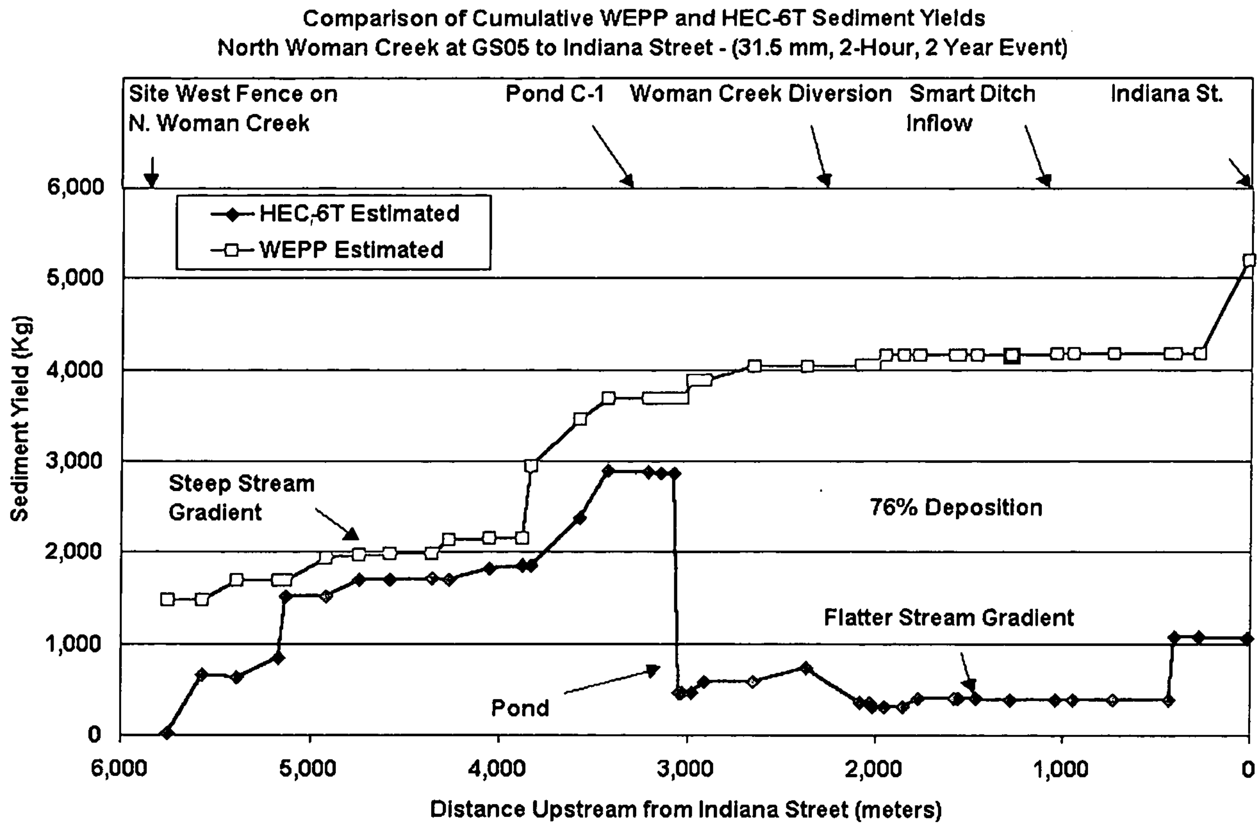

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Figure C- 9. WEPP and HEC-6T Results for the SID, 6-Hour, 10-Year Event

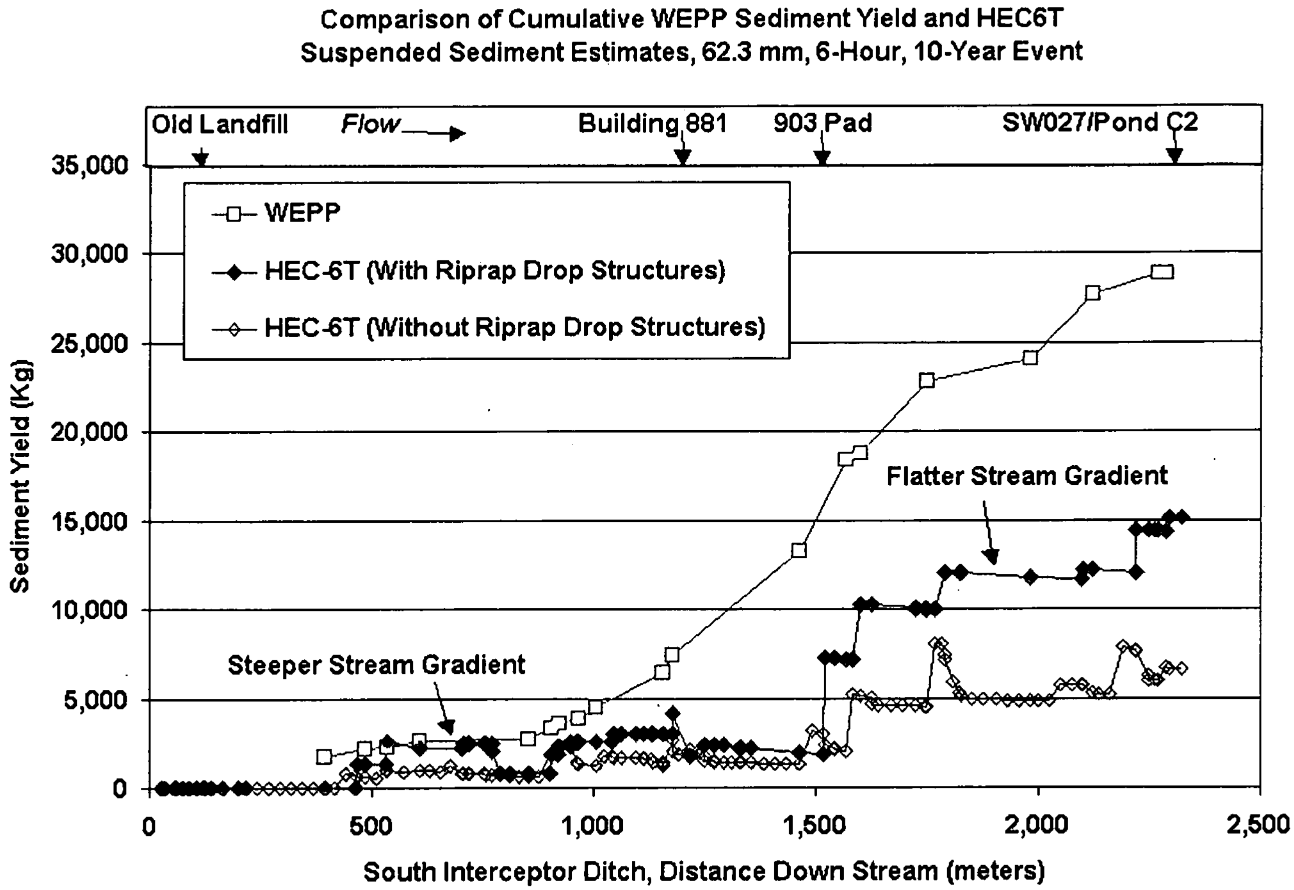

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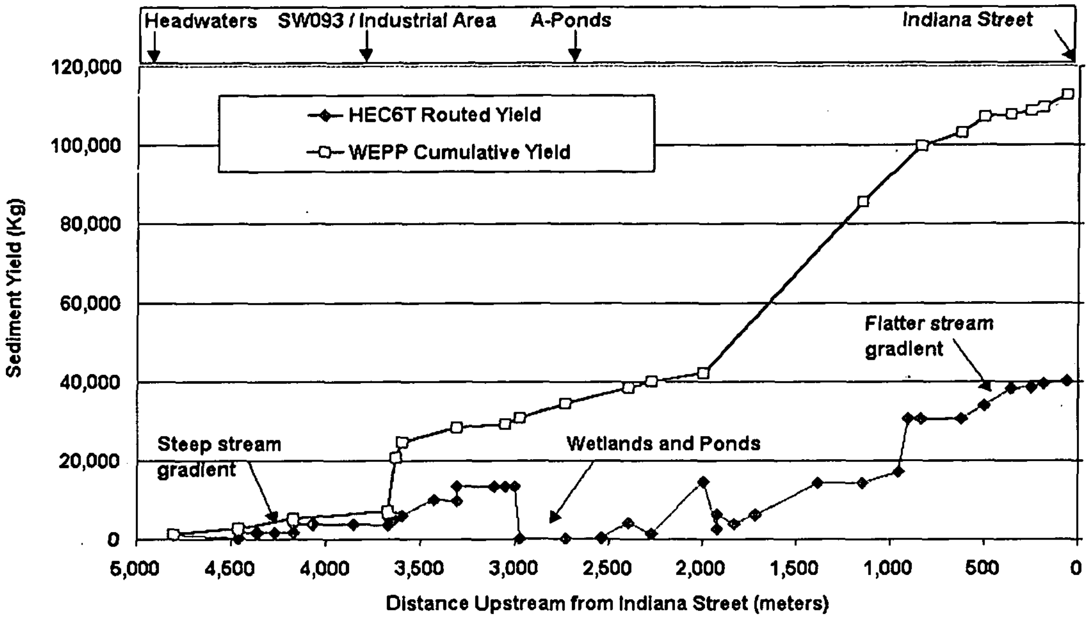
Figure C- 10. WEPP and HEC-6T Sediment Yields for Walnut Creek



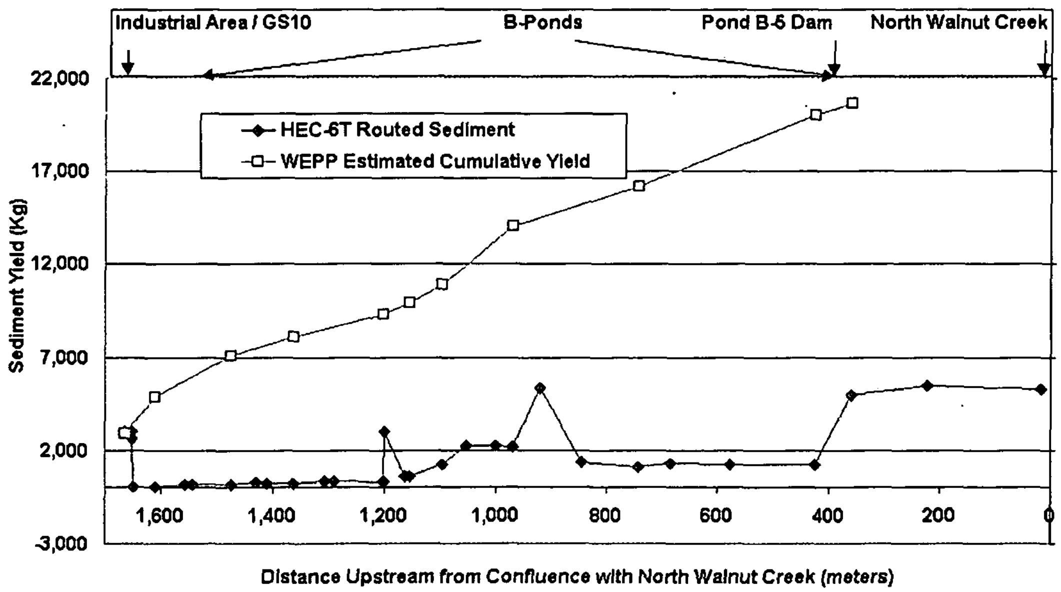


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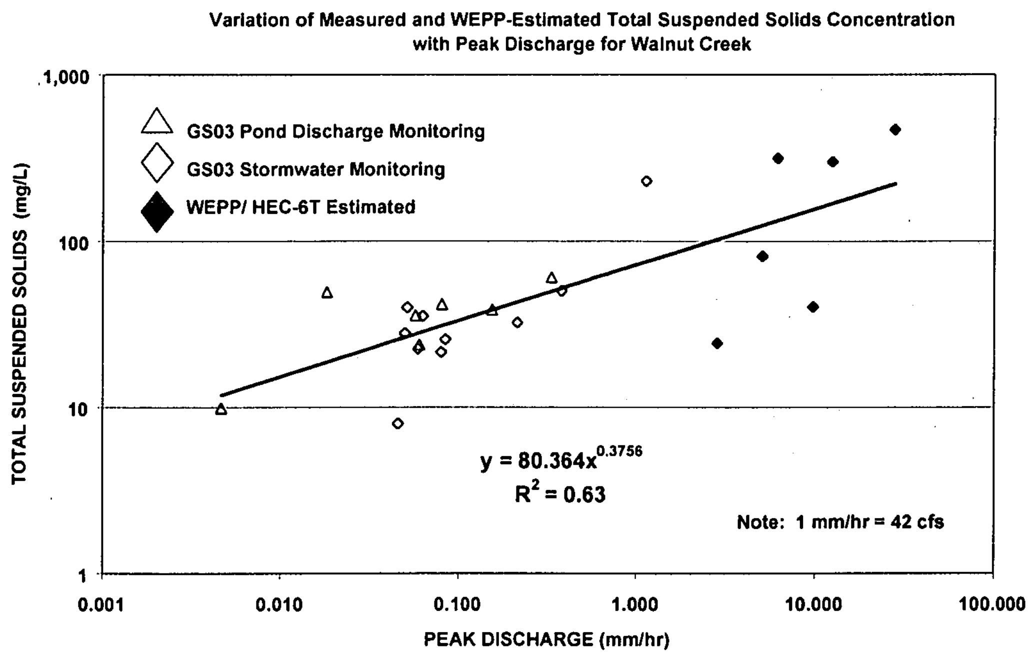
Figure C- 11. Comparison of WEPP/HEC-6T Estimated Total Suspended Solids Concentrations with Measured Data



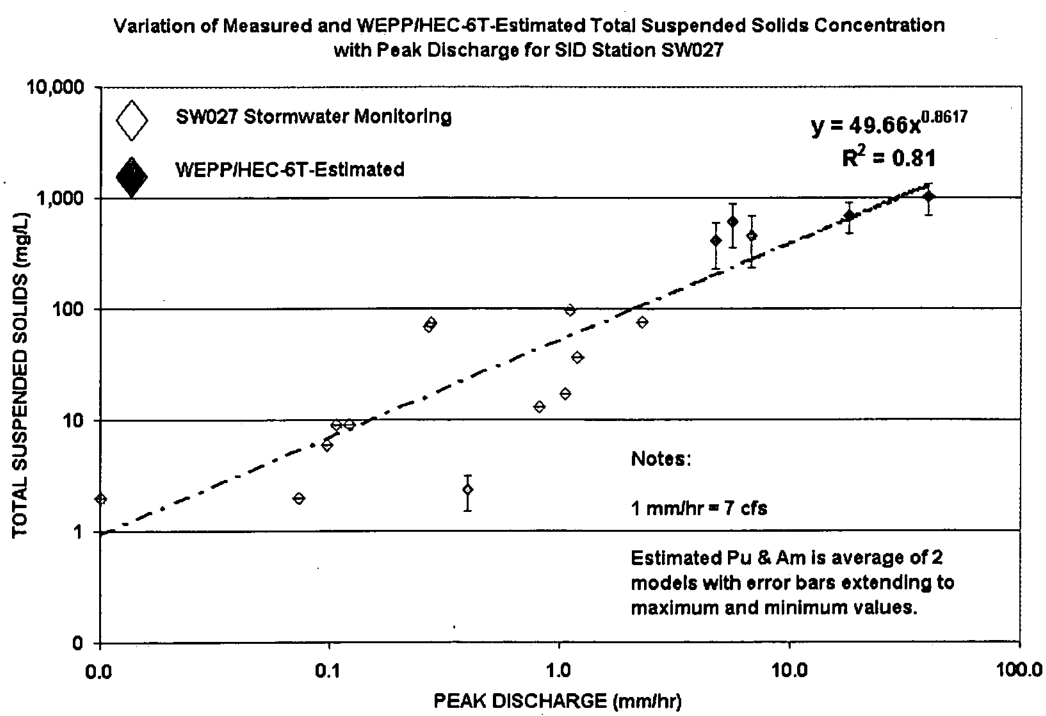


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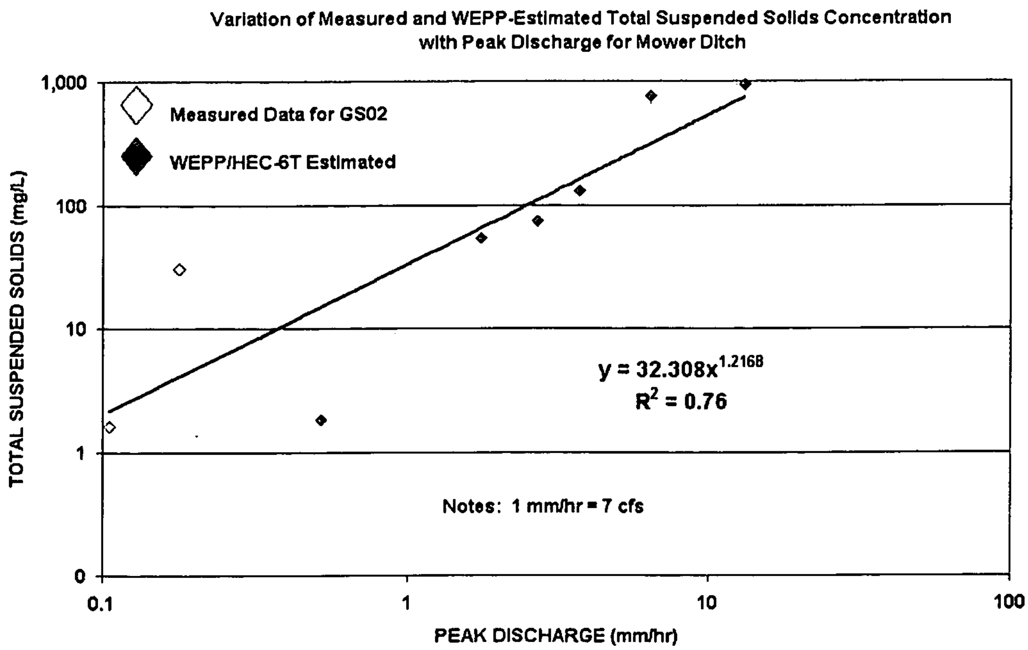
Figure C- 12. Comparison of WEPP/HEC-6T Estimated Total Suspended Solids Concentrations with Measured Data



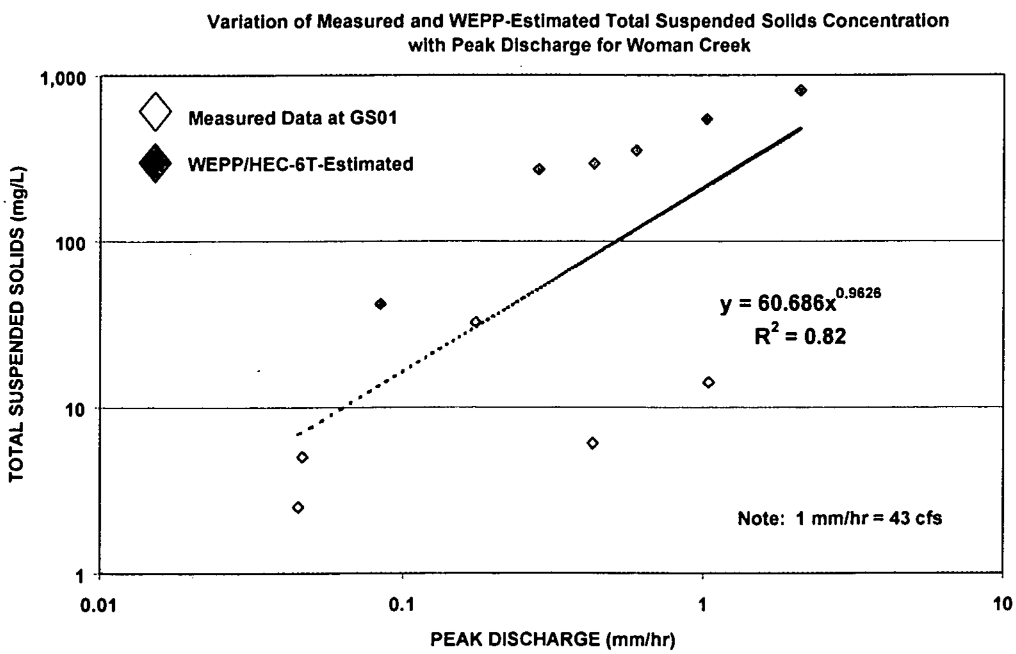


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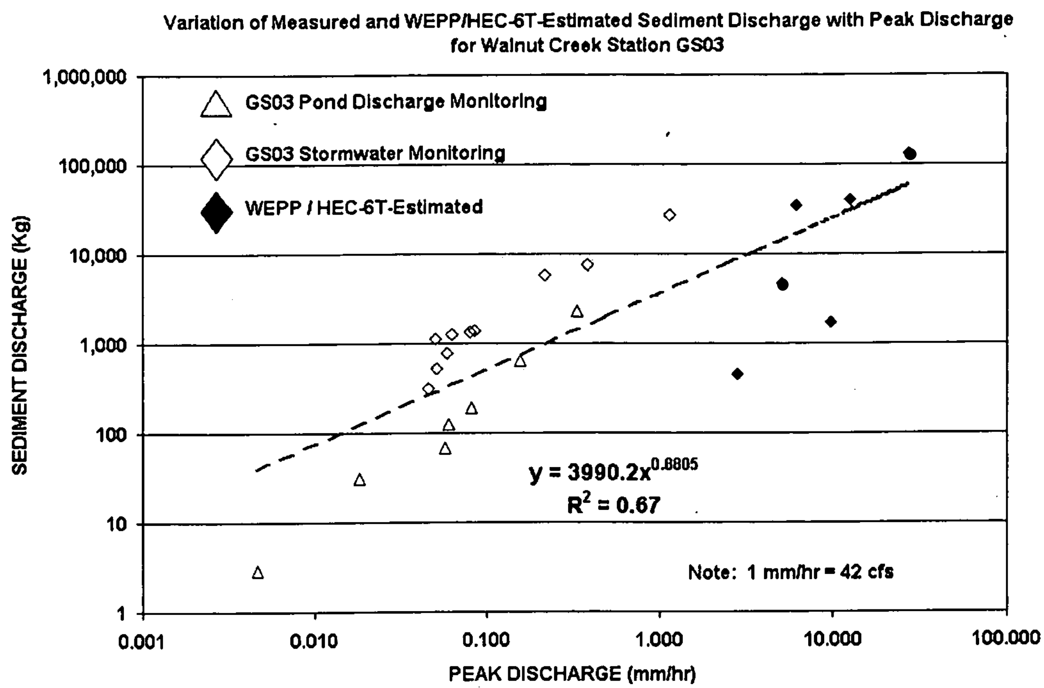
Figure C- 13. Comparison of Measured and Simulated Sediment Yields



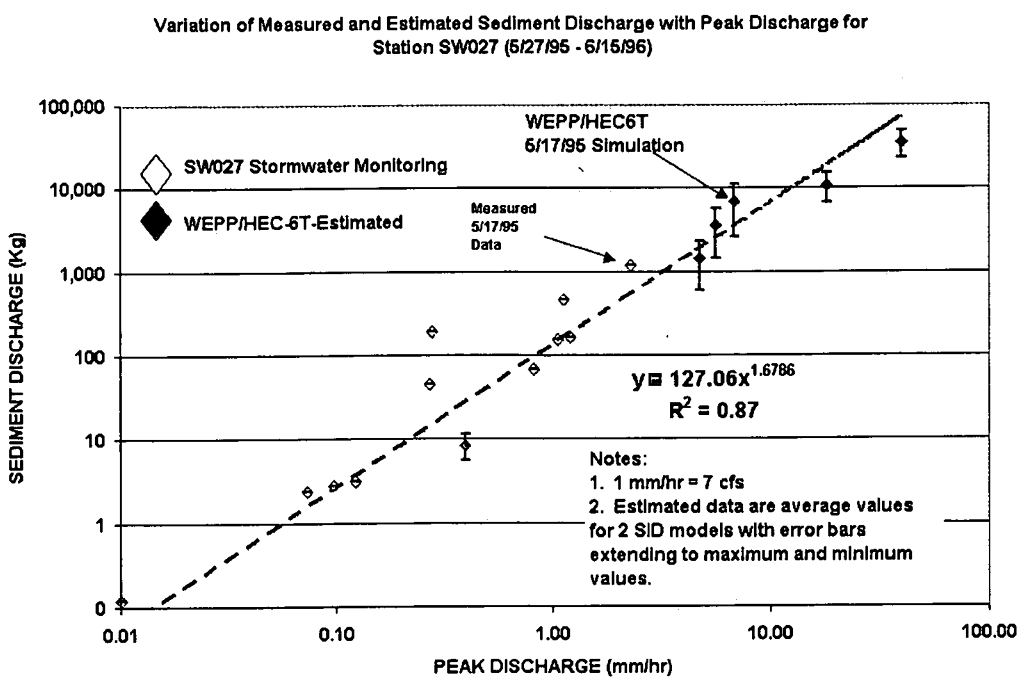


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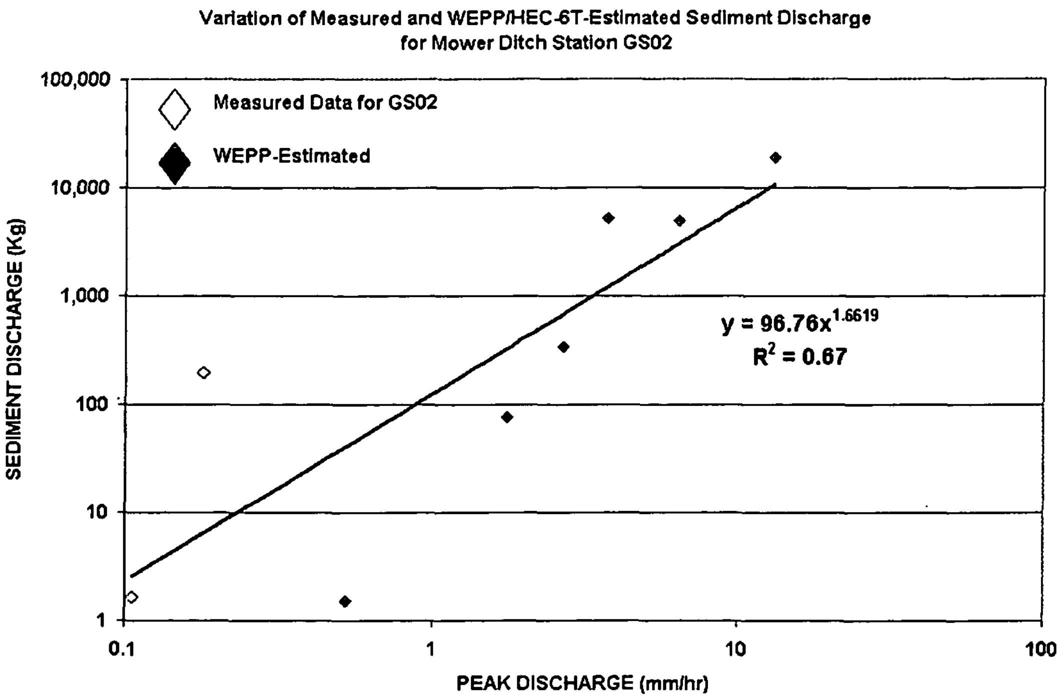
Figure C- 14. Comparison of Measured and Simulated Sediment Yields



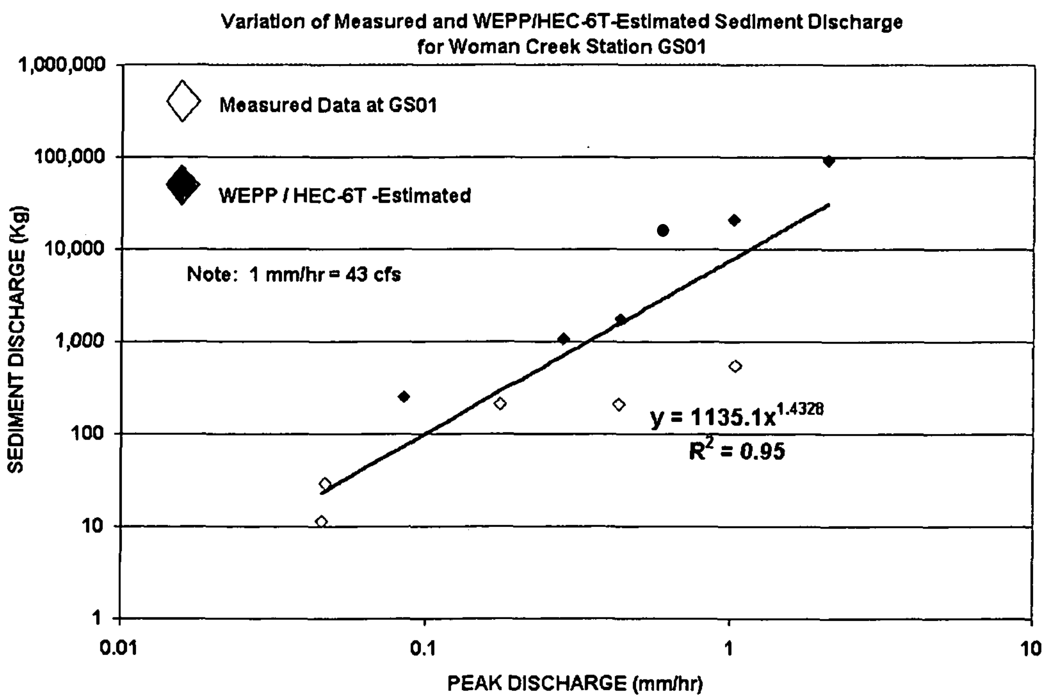


Figure C- 15. Comparison of Measured and Simulated Sediment Deposition in the SID

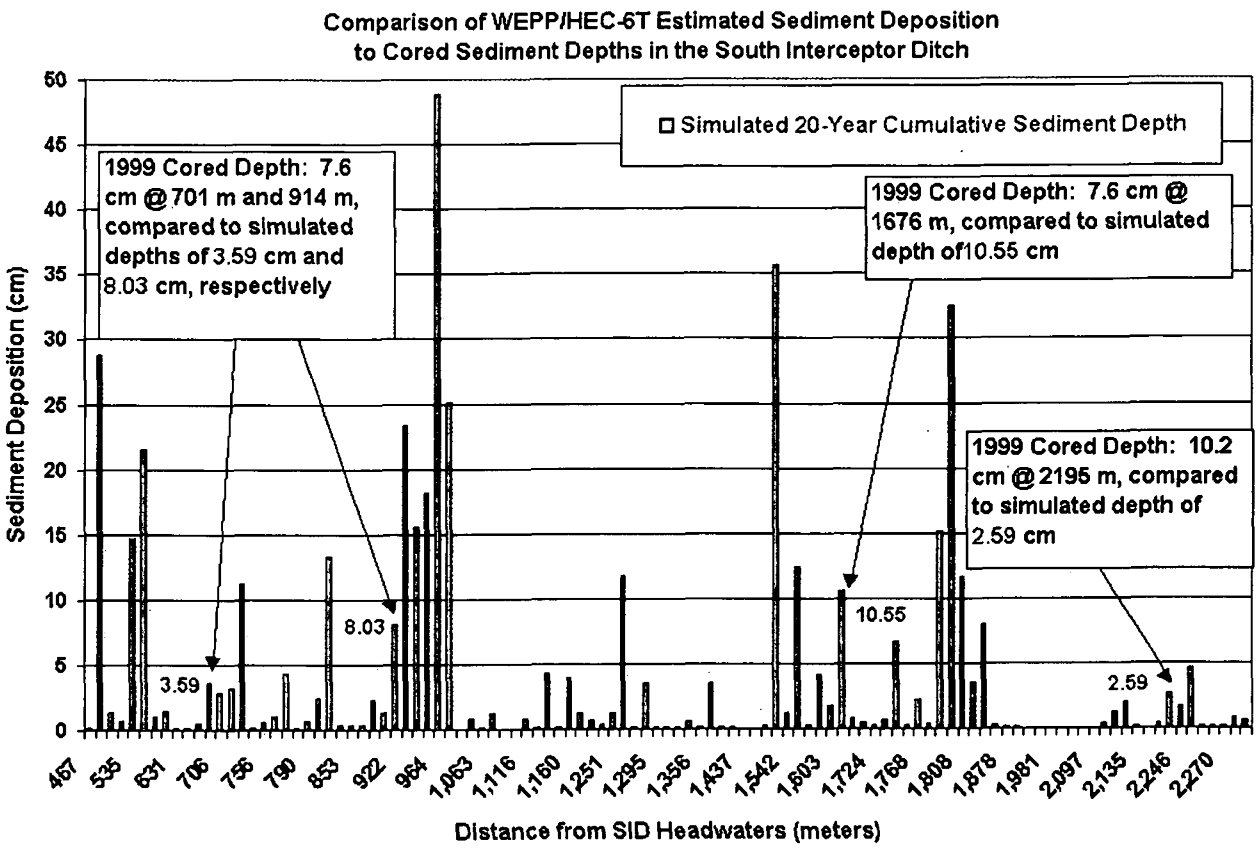
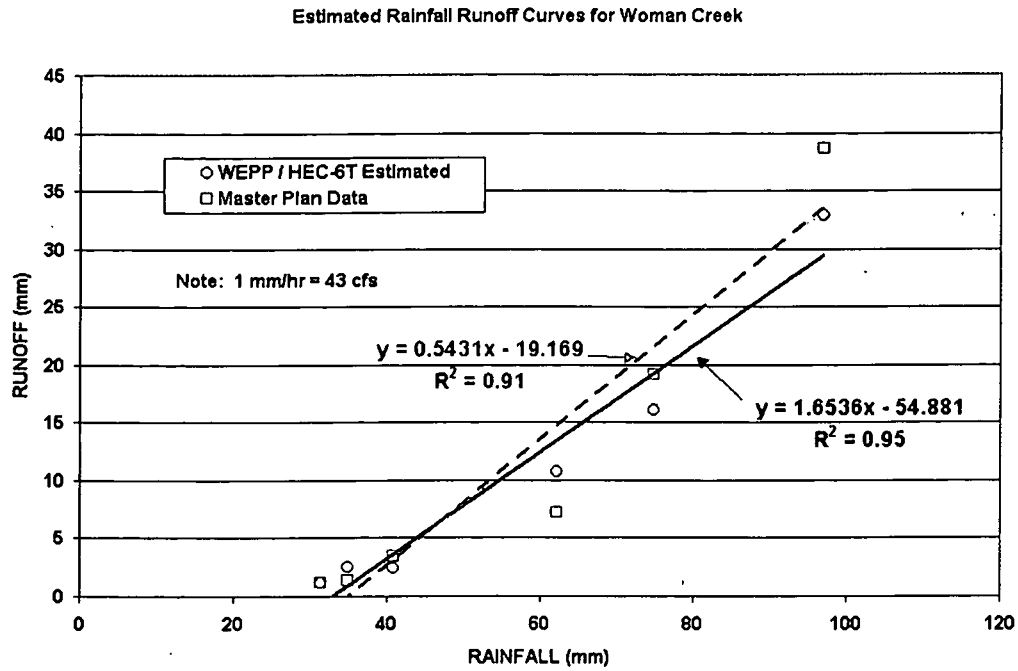


Figure C- 16. Simulated SID and Woman Creek Rainfall Runoff Curves



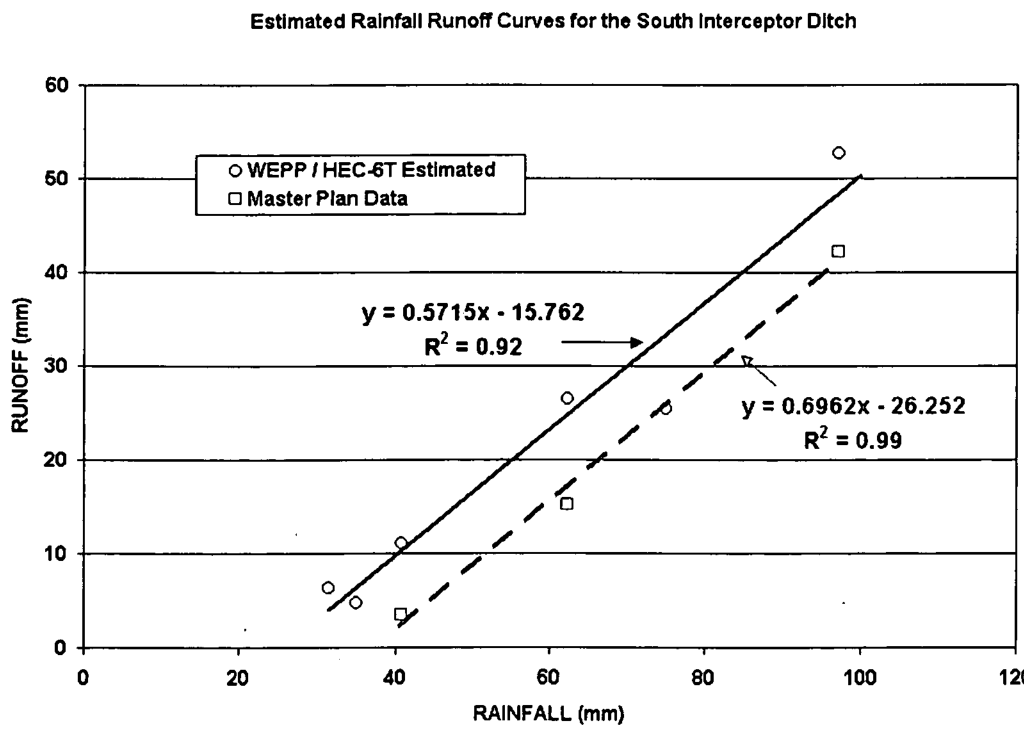
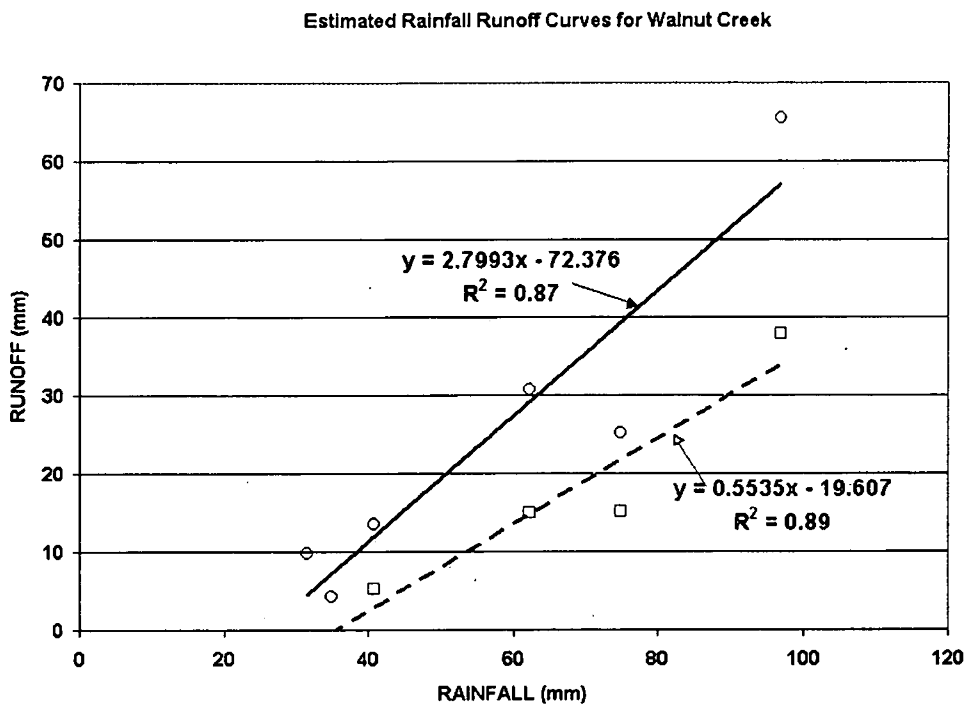


Figure C- 17. Simulated Mower Ditch and Walnut Creek Rainfall Runoff Curves



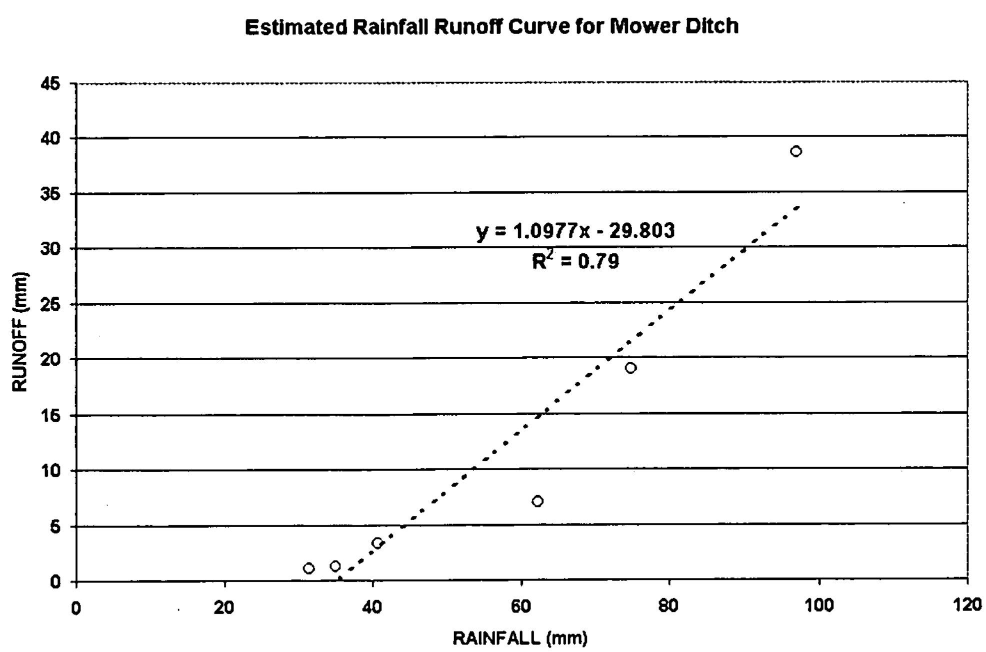


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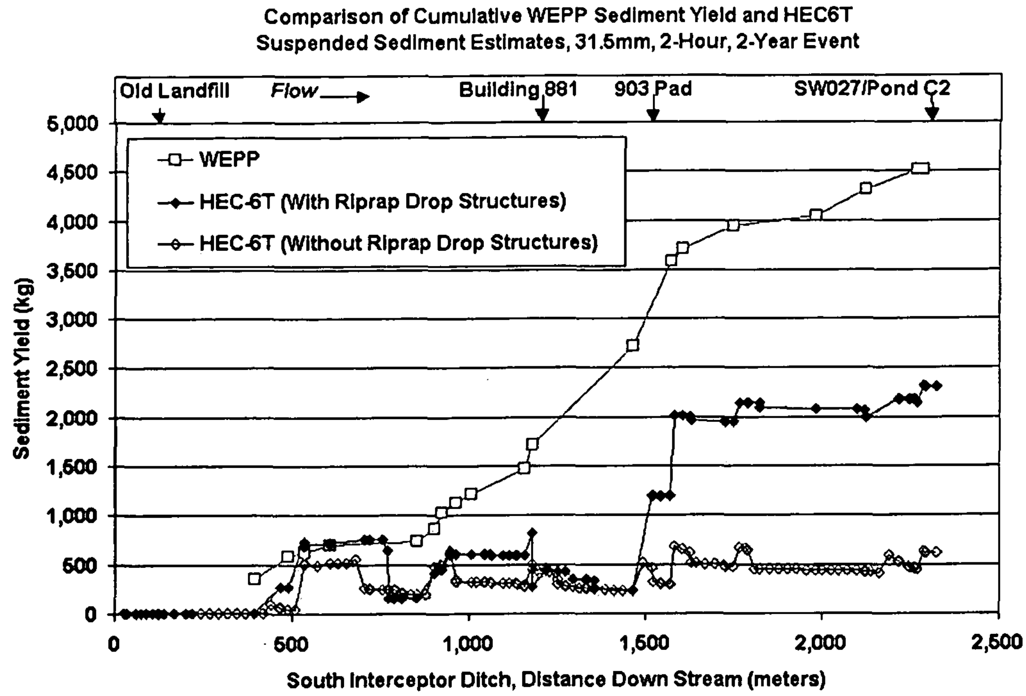
Figure C- 18. WEPP and HEC-6T Sediment Yields for the SID, 2-Year Events



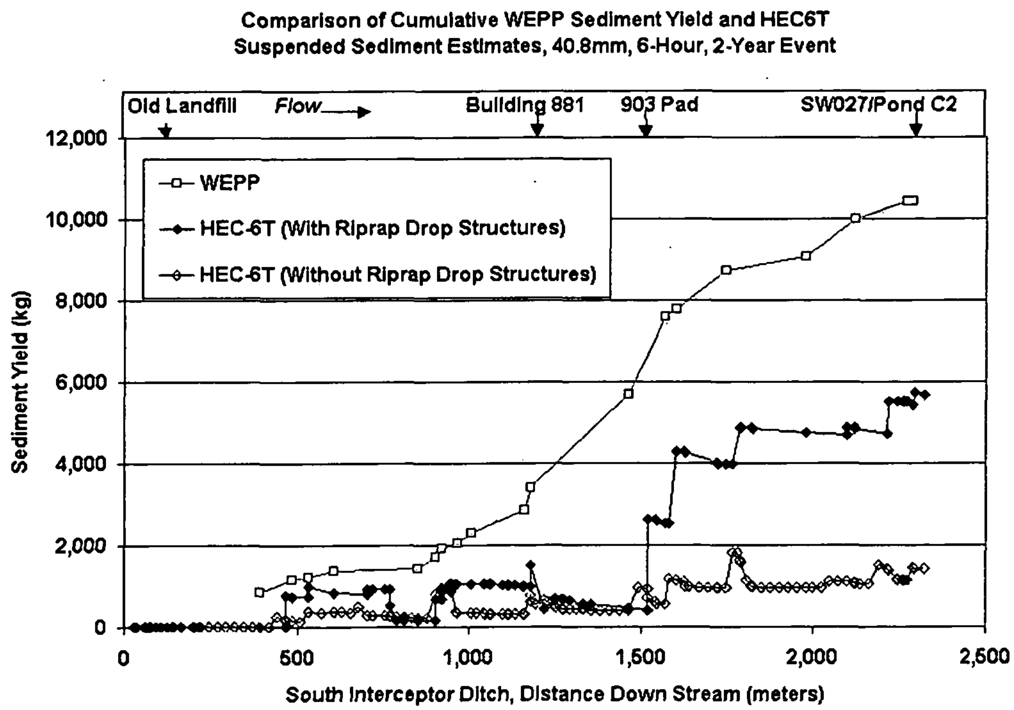
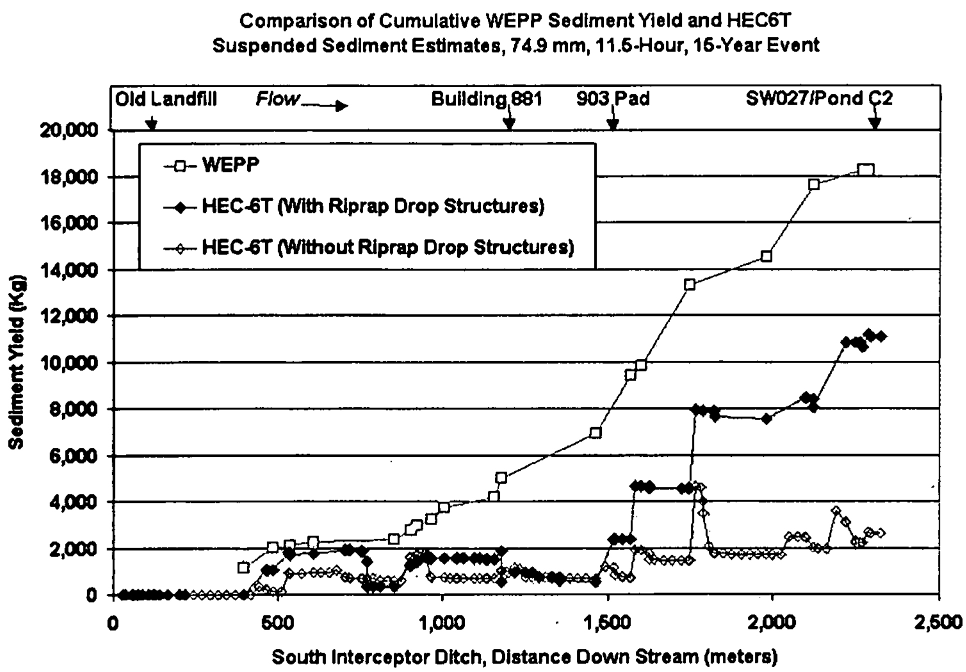


Figure C- 19. WEPP and HEC-6T Sediment Yields for the SID, 35-mm and May 17, 1995 Events



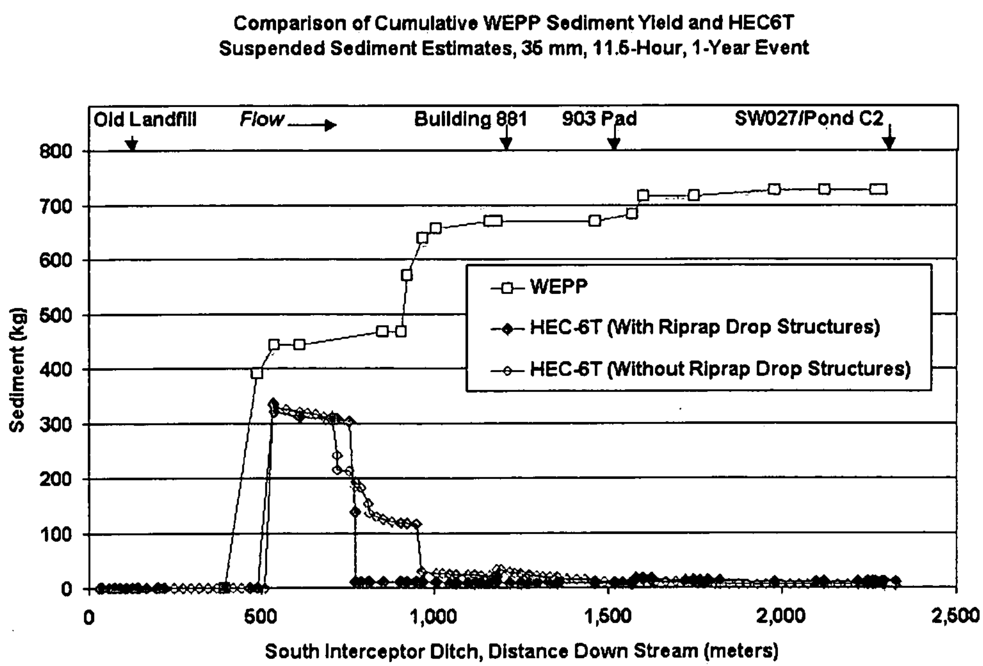
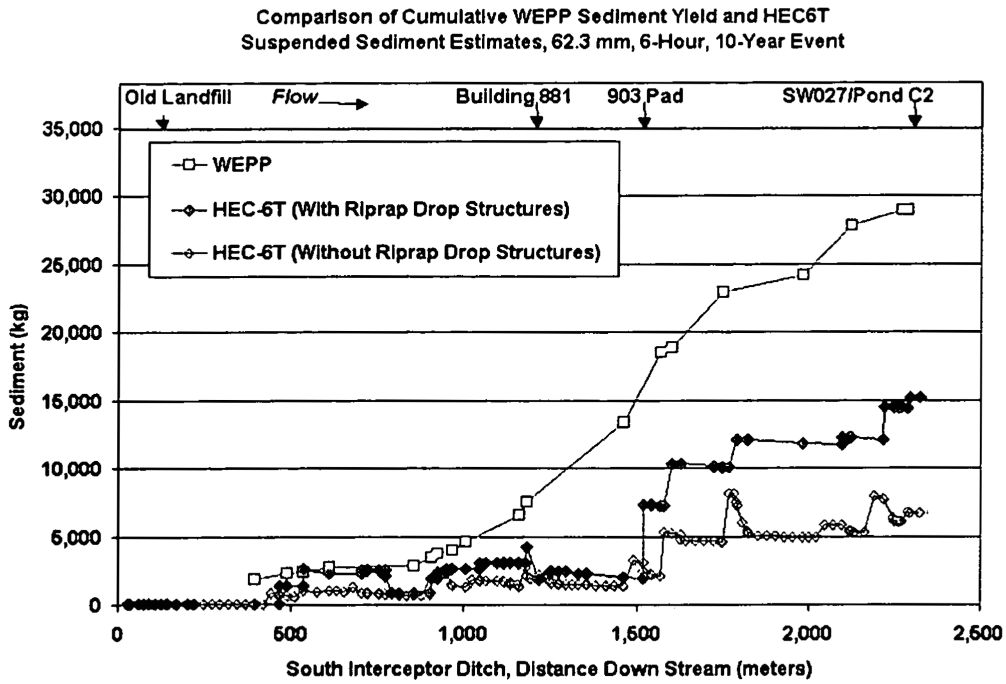


Figure C- 20. WEPP and HEC-6T Sediment Yields for the SID, 10- and 100-Year Events



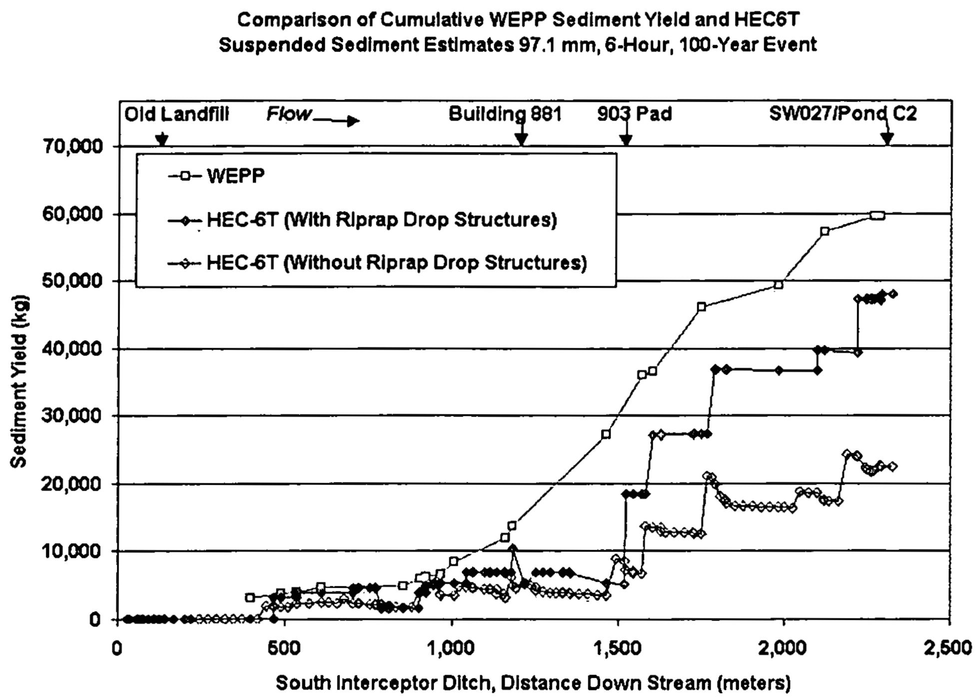


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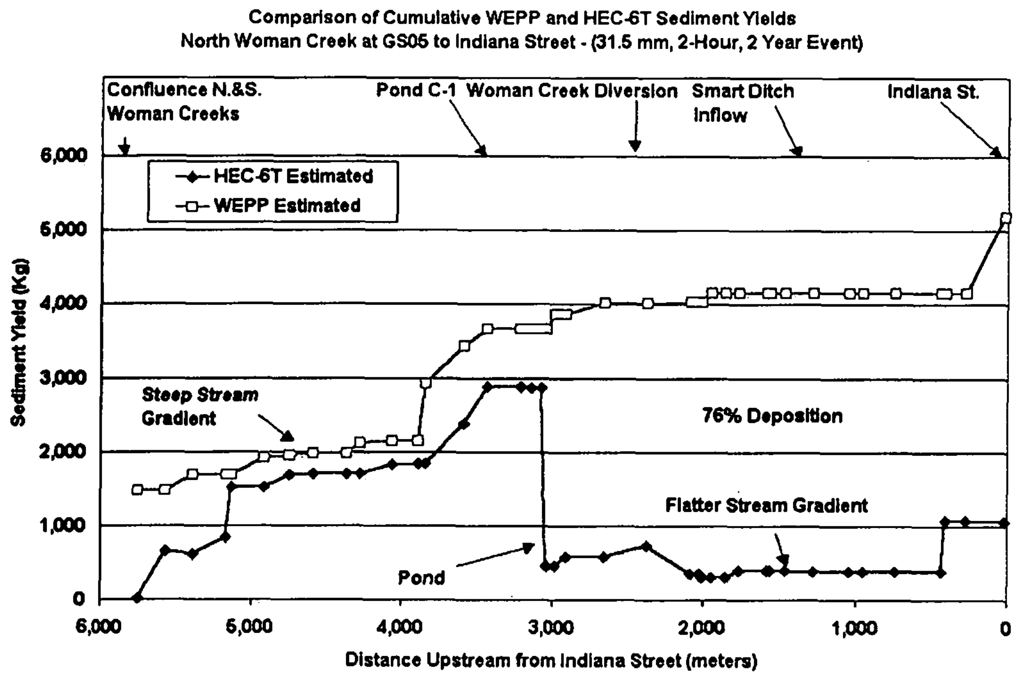
Figure C- 21. WEPP and HEC-6T Sediment Yields for Woman Creek, 2-Year Events



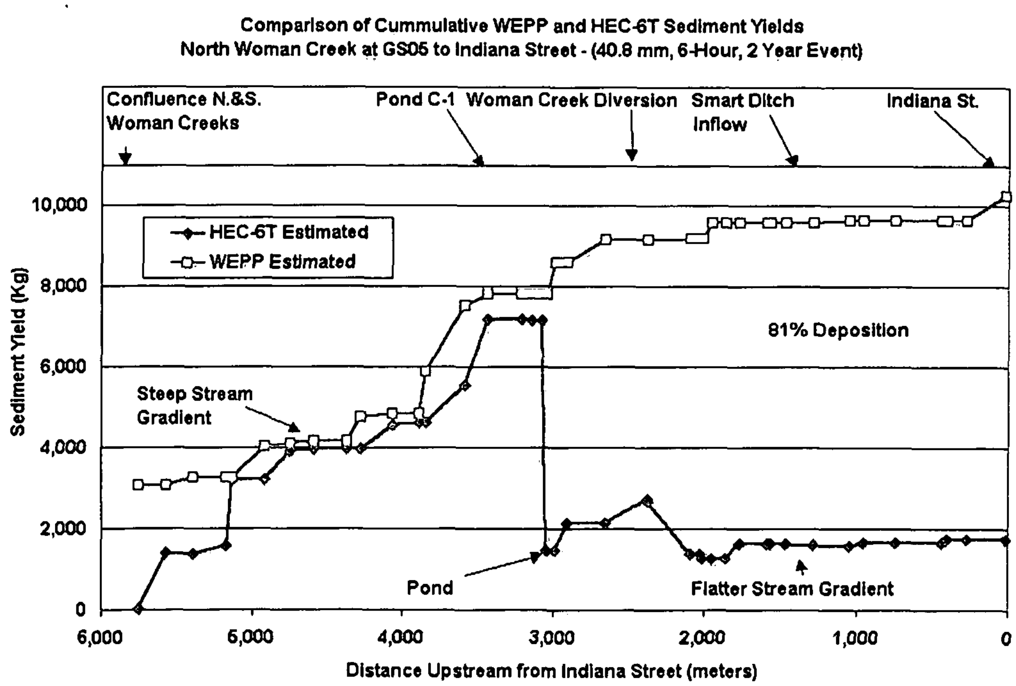
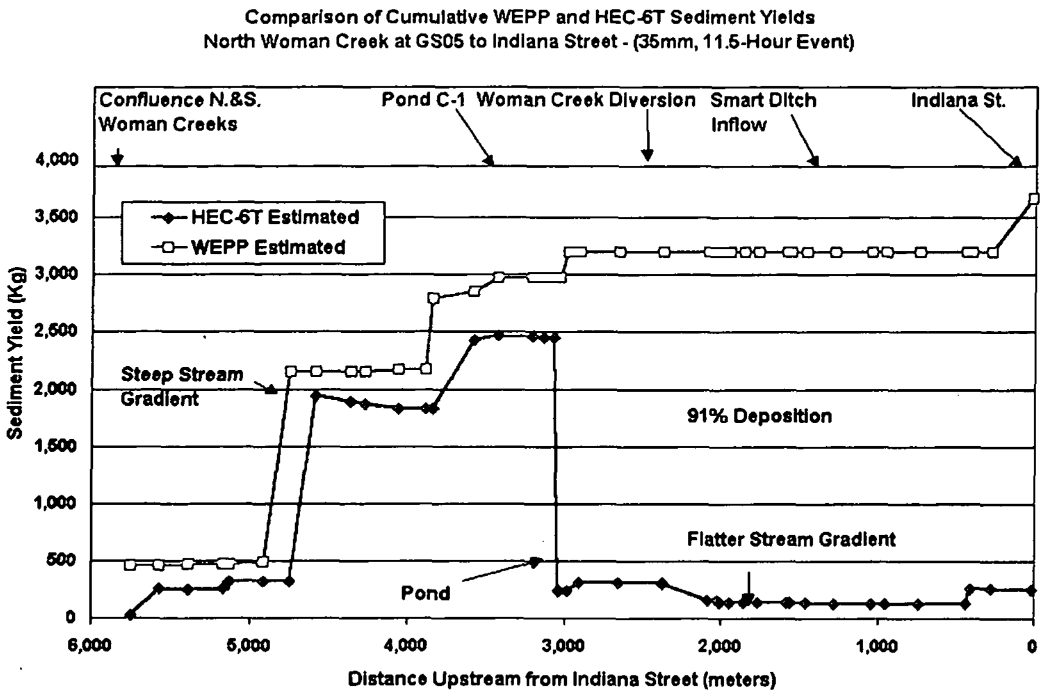


Figure C- 22. WEPP and HEC-6T Sediment Yields for Woman Creek, 35-mm and May 17, 1995 Events



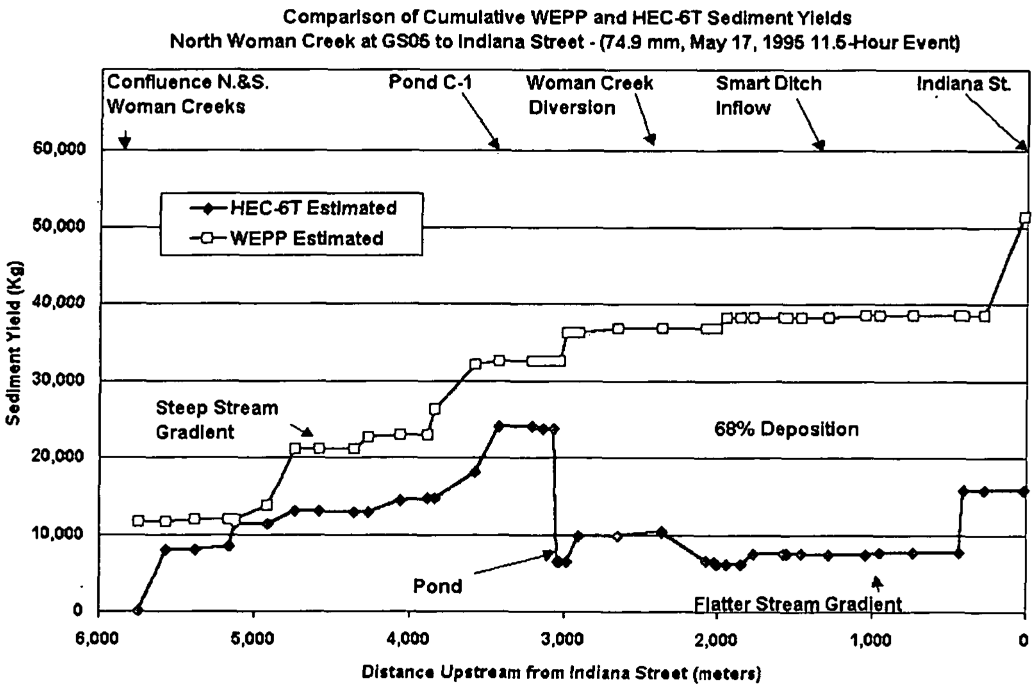
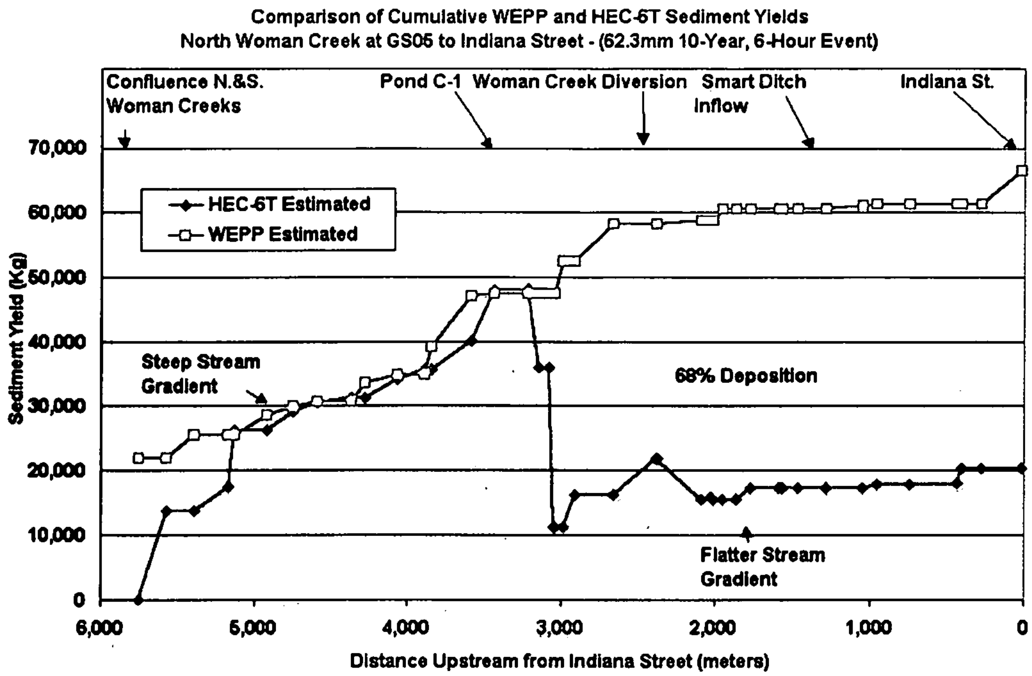


Figure C- 23. WEPP and HEC-6T Sediment Yields for Woman Creek, 10- and 100-Year Events



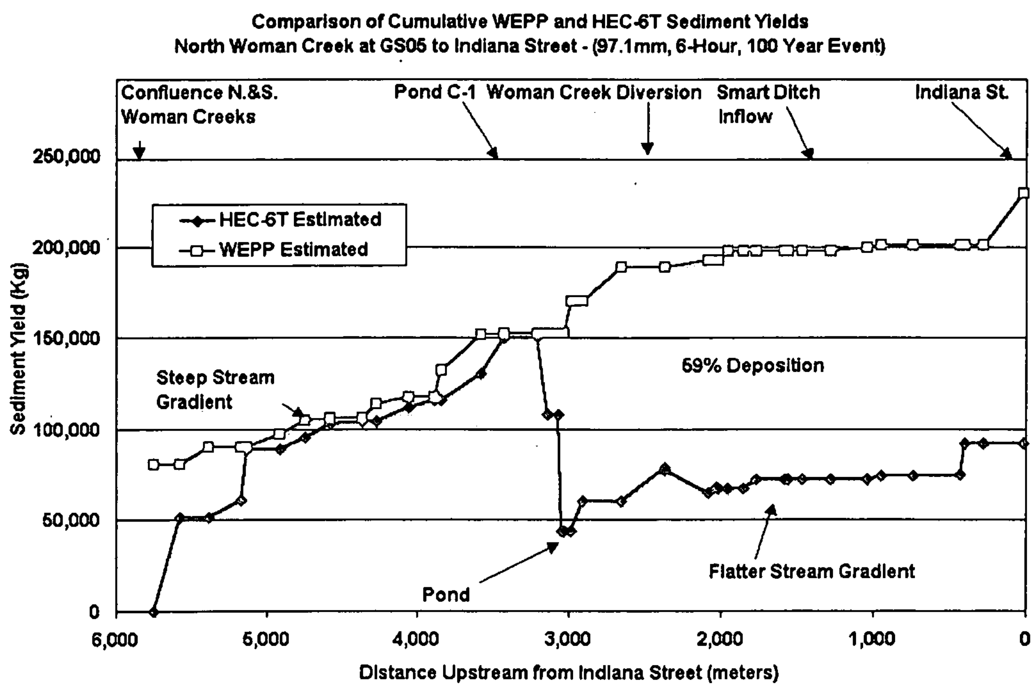


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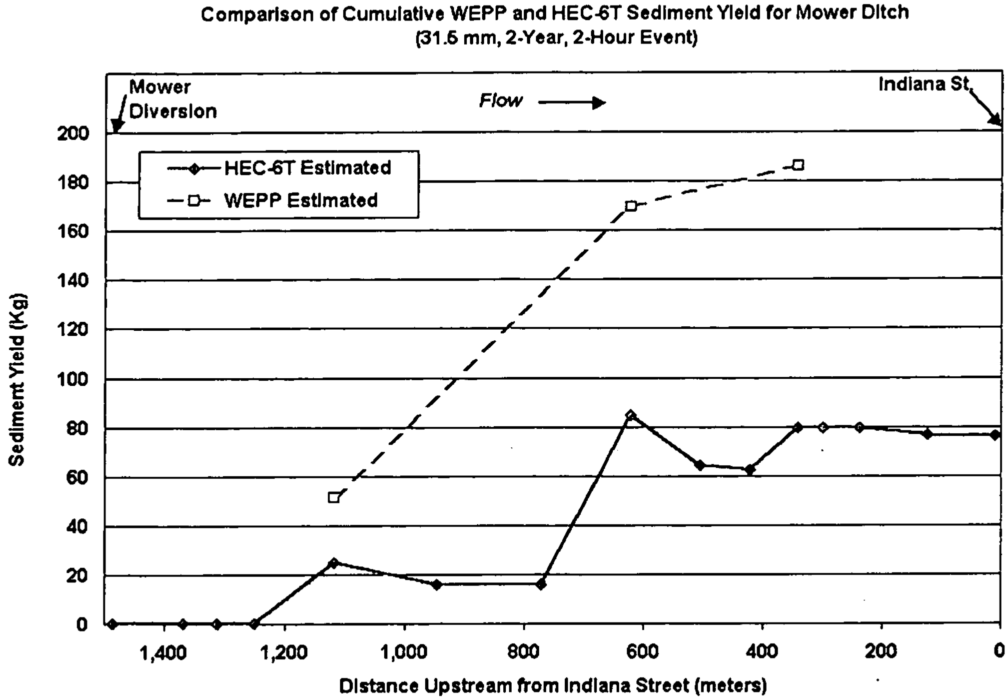
Figure C- 24. WEPP and HEC-6T Sediment Yields for Mower Ditch, 2-Year Events



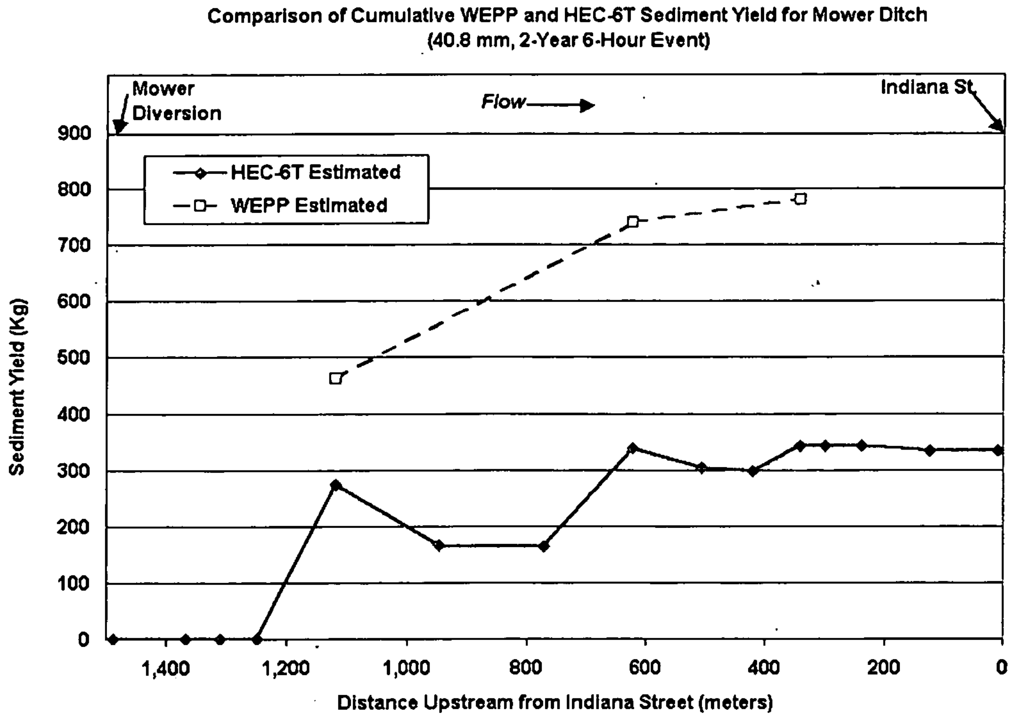


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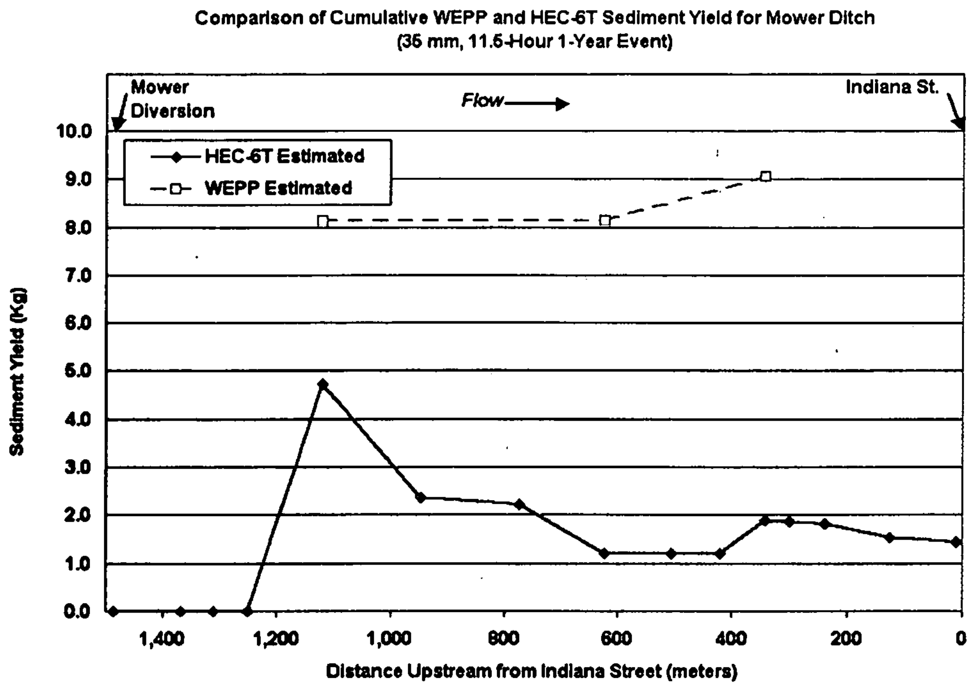
Figure C- 25. WEPP and HEC-6T Sediment Yields for Mower Ditch, 35-mm and May 17, 1995 Events



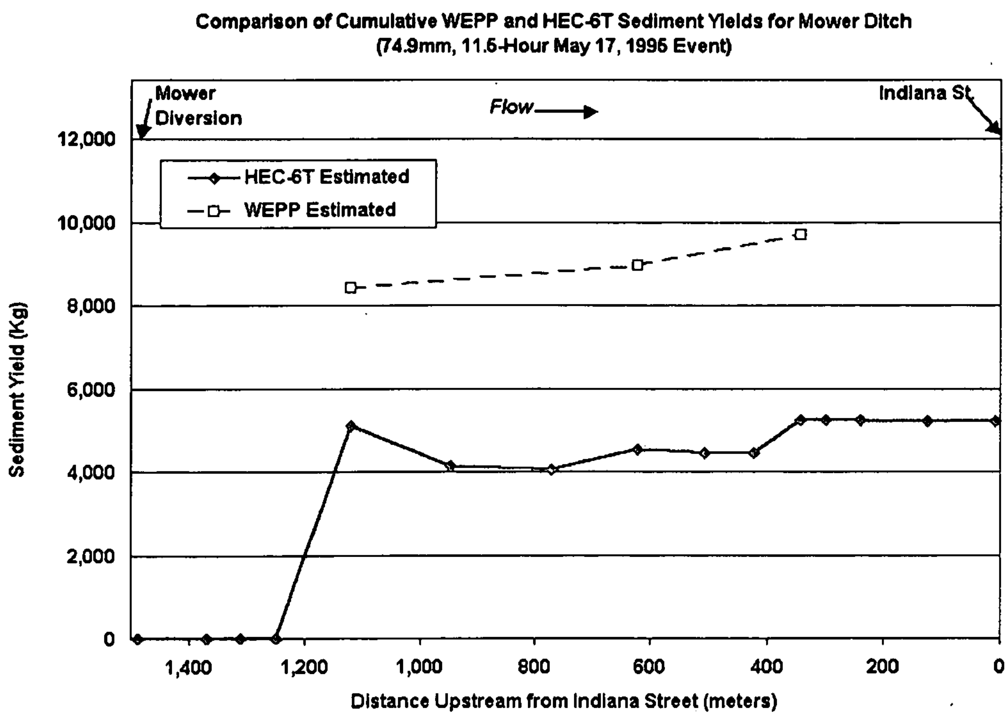
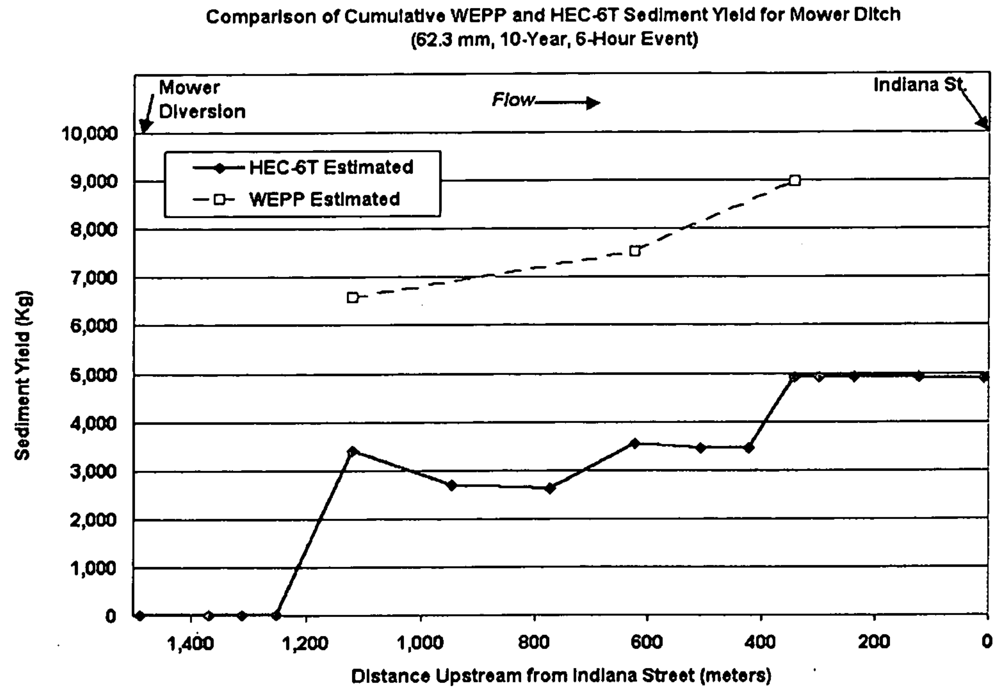


Figure C- 26. WEPP and HEC-6T Sediment Yields for Mower Ditch, 10- and 100-Year Events



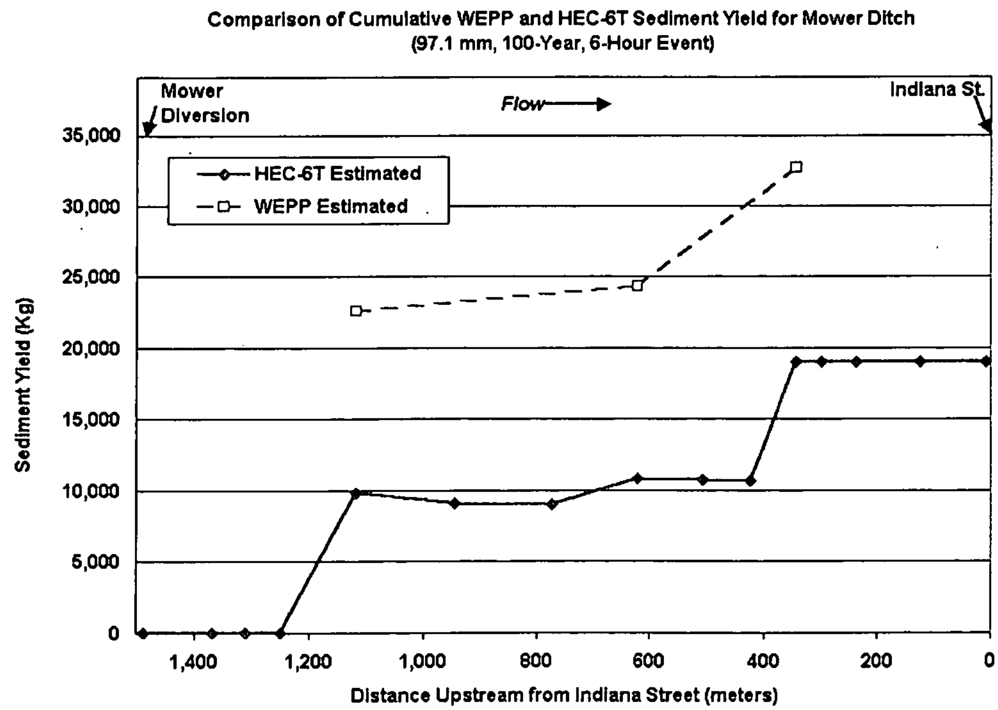


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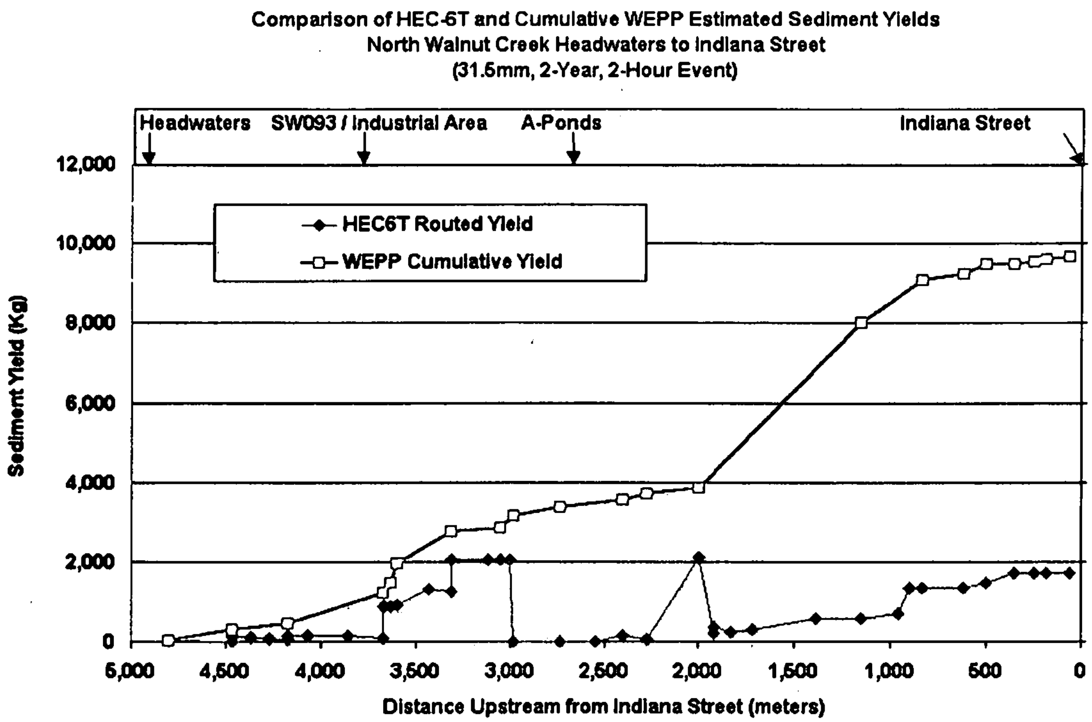
Figure C- 27. WEPP and HEC-6T Sediment Yields for Walnut Creek, 2-Year Events



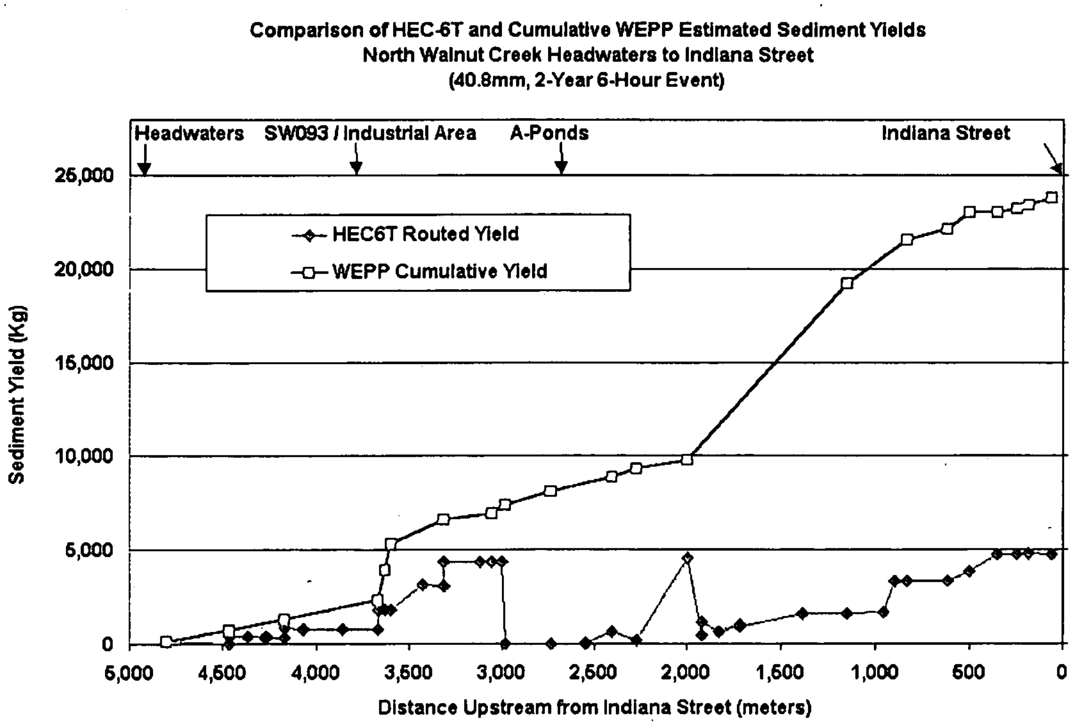


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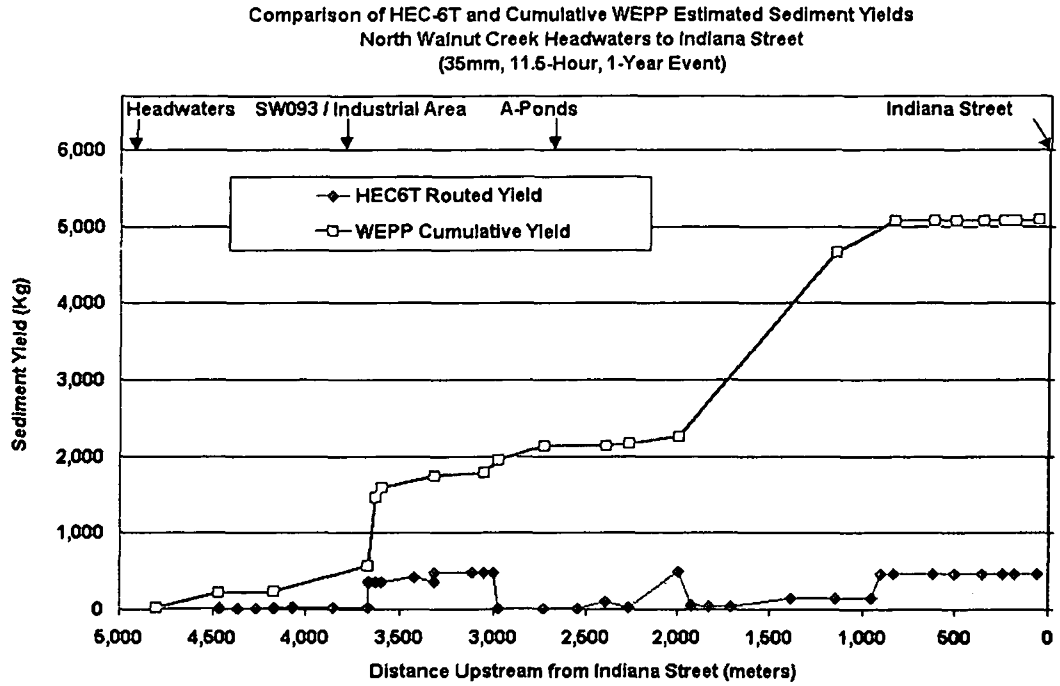
Figure C- 28. WEPP and HEC-6T Sediment Yields for Walnut Creek, 35-mm and May 17, 1995 Events



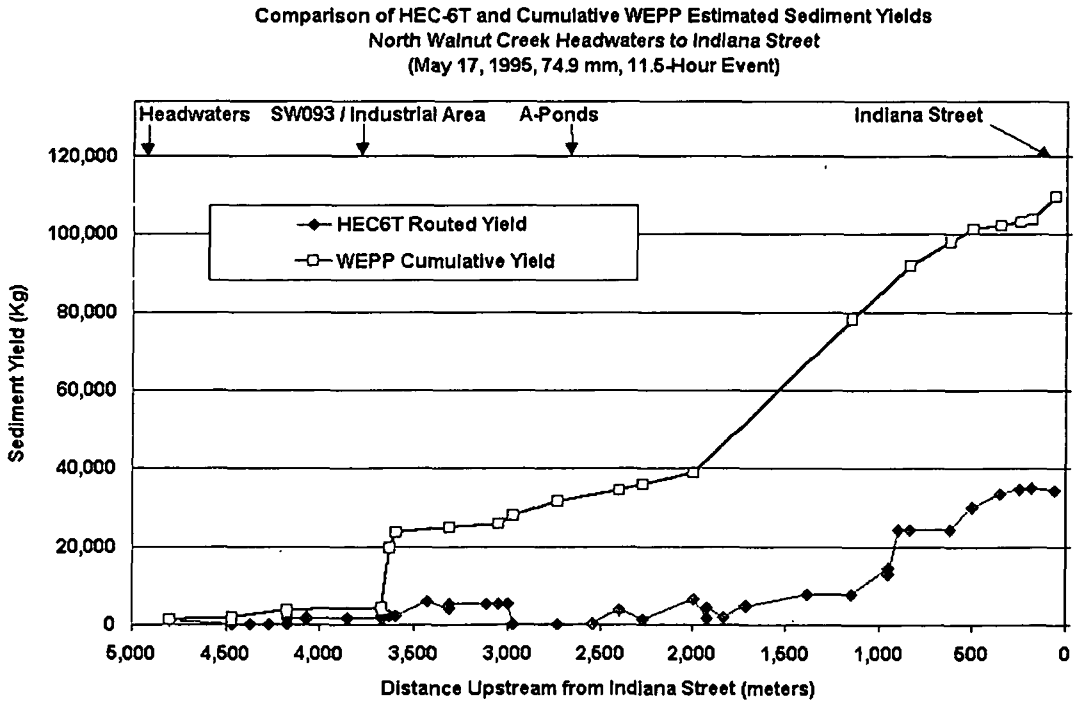


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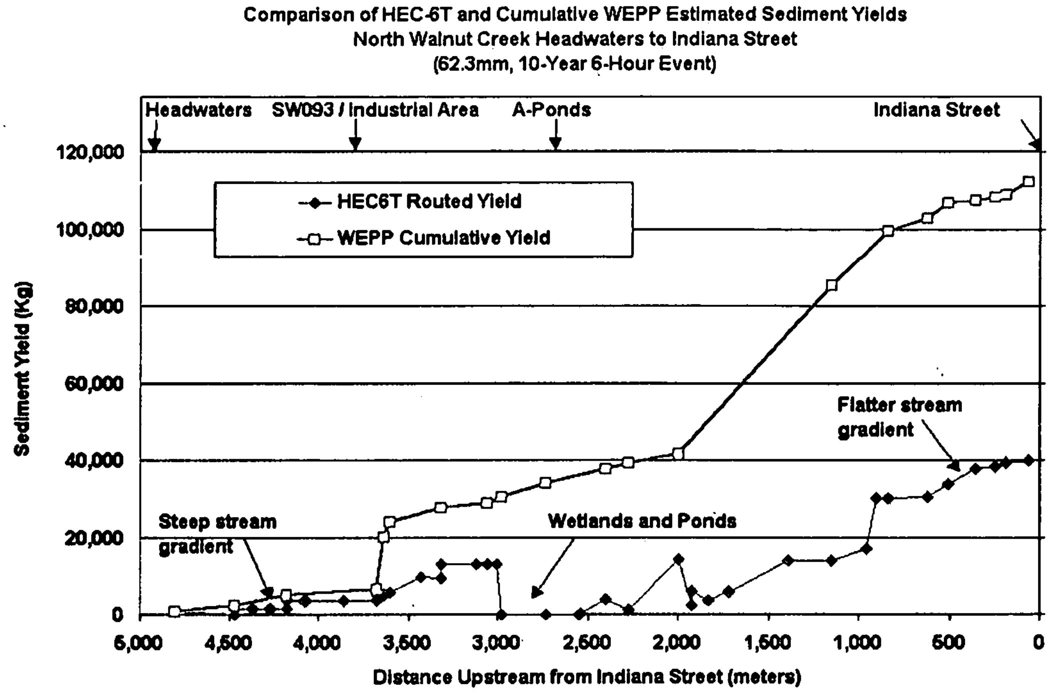
Figure C- 29. WEPP and HEC-6T Sediment Yields for Walnut Creek, 10- and 100-Year Events



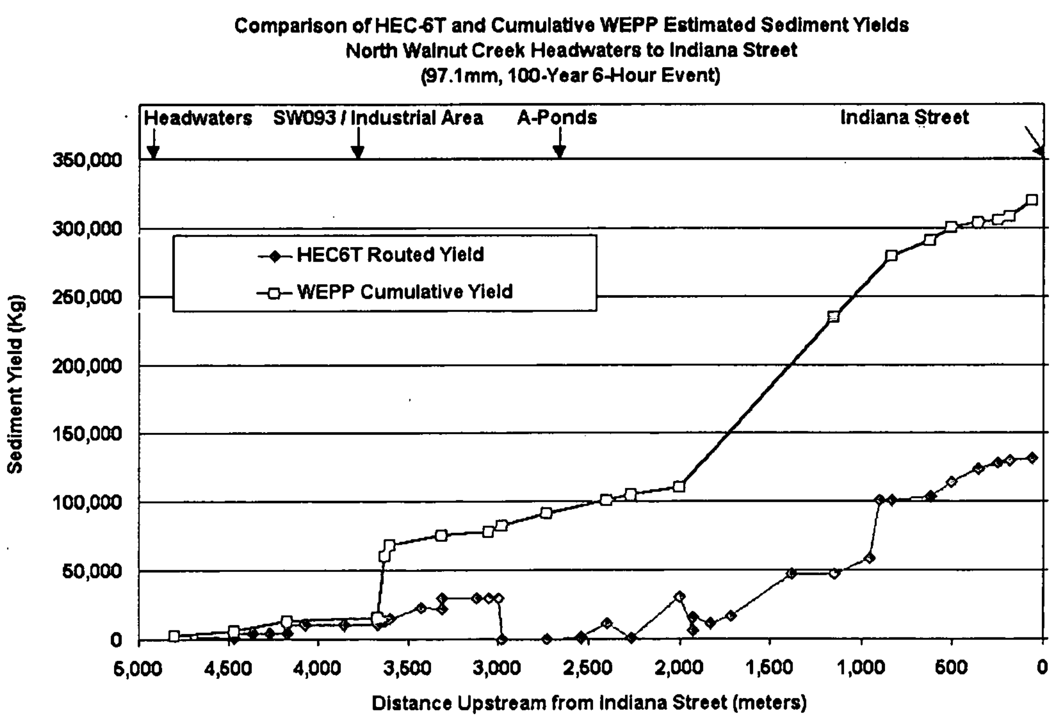


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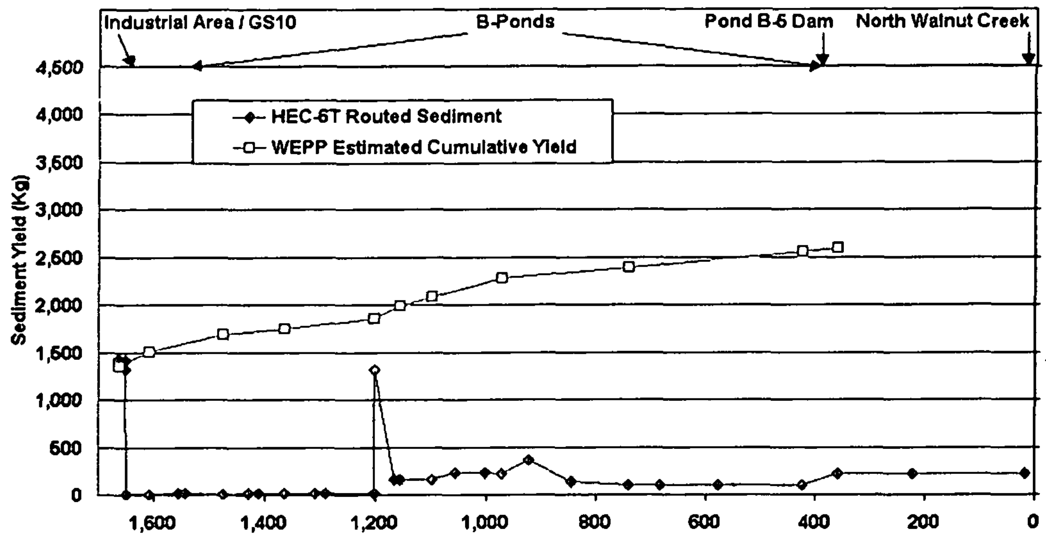
Figure C- 30. WEPP and HEC-6T Sediment Yields for South Walnut Creek, 2-Year Events

Comparison of HEC-6T and WEPP Cumulative Sediment Yields
South Walnut Creek from Industrial Area to
Confluence with North Walnut Creek (31.5mm, 2-Year, 2-Hour Event)



Comparison of HEC-6T and WEPP Cumulative Sediment Yields
South Walnut Creek from Industrial Area to
Confluence with North Walnut Creek 40.8mm, 2-Year 6-Hour Event

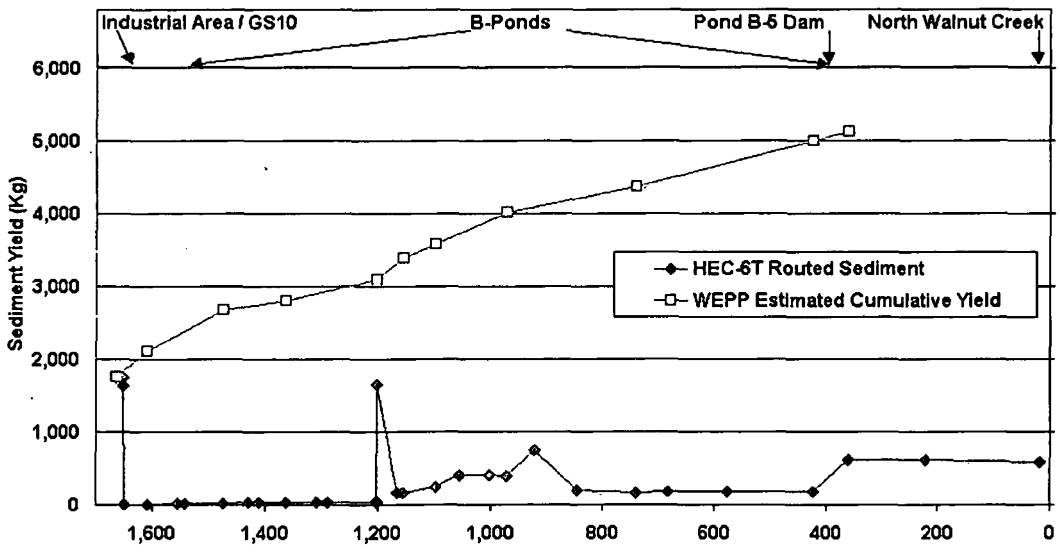


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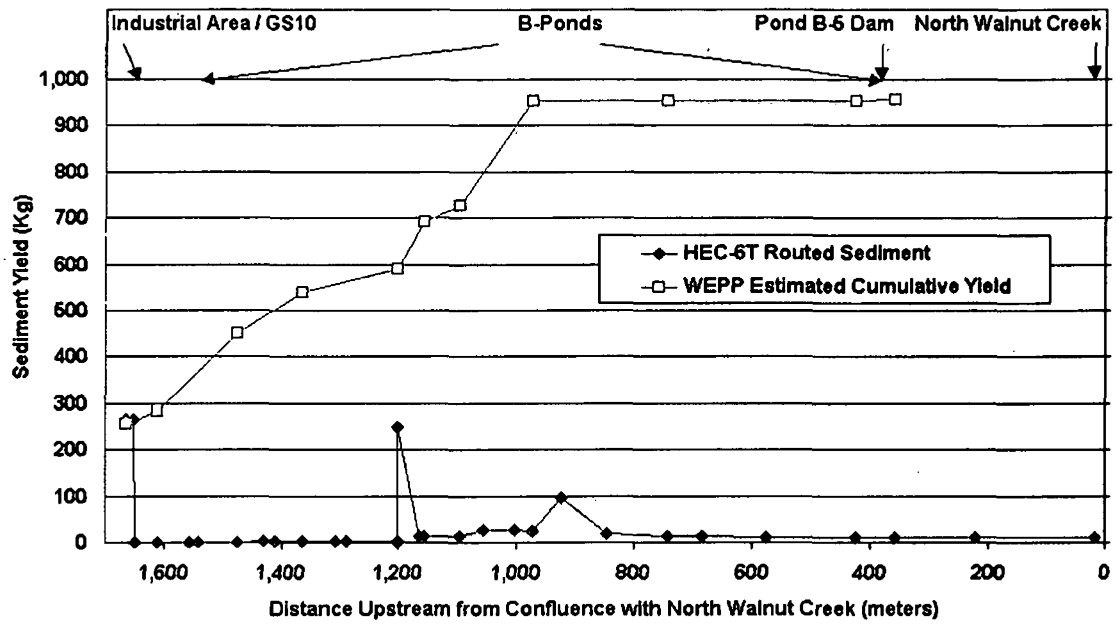
Figure C- 31. WEPP and HEC-6T Sediment Yields for South Walnut Creek, 35-mm and May 17, 1995 Events

Comparison of HEC-6T and WEPP Cumulative Sediment Yields
South Walnut Creek from Industrial Area to
Confluence with North Walnut Creek (35mm, 11.5-Hour, 1-Year Event)



Comparison of HEC-6T and WEPP Cumulative Sediment Yields
South Walnut Creek from Industrial Area to
Confluence with North Walnut Creek (May 17, 1995, 74.9 mm, 11.5-Hour Event)

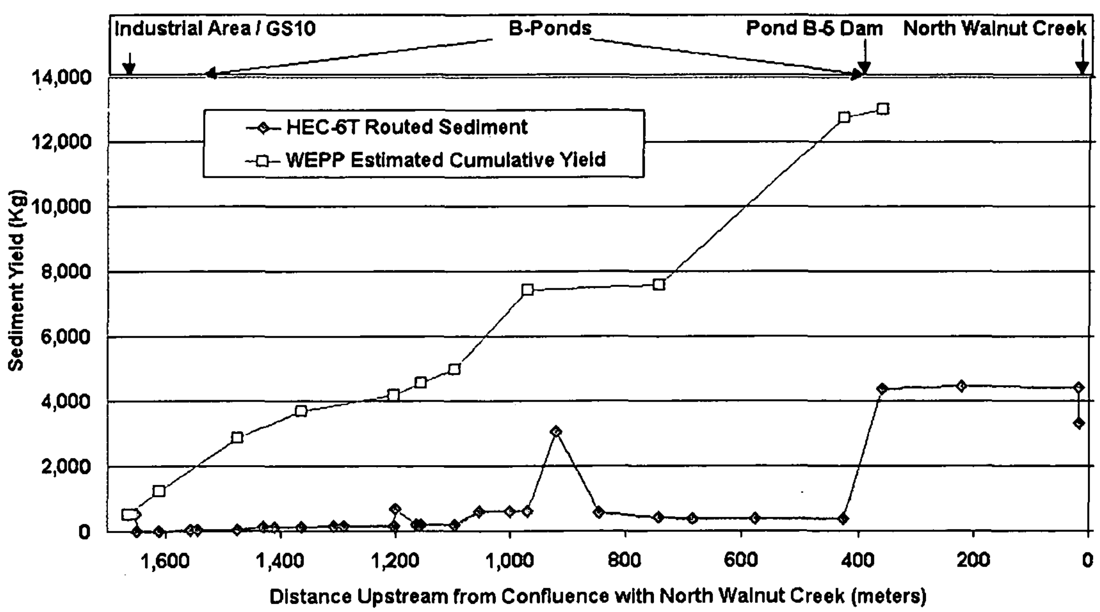


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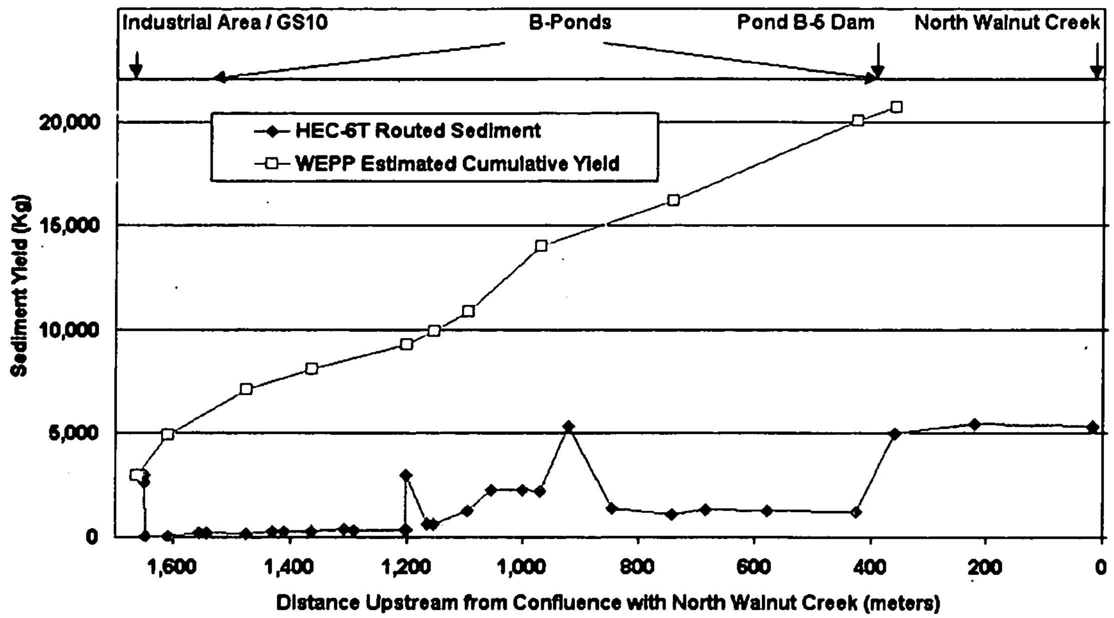
Figure C- 32. WEPP and HEC-6T Sediment Yields for South Walnut Creek, 10- and 100-Year Events

Comparison of HEC-6T and WEPP Cumulative Sediment Yields
South Walnut Creek from Industrial Area to
Confluence with North Walnut Creek (62.3mm, 10-Year 6-Hour Event)



Comparison of HEC-6T and WEPP Cumulative Sediment Yields
South Walnut Creek from Industrial Area to
Confluence with North Walnut Creek (97.1mm, 100-Year 6-Hour Event)

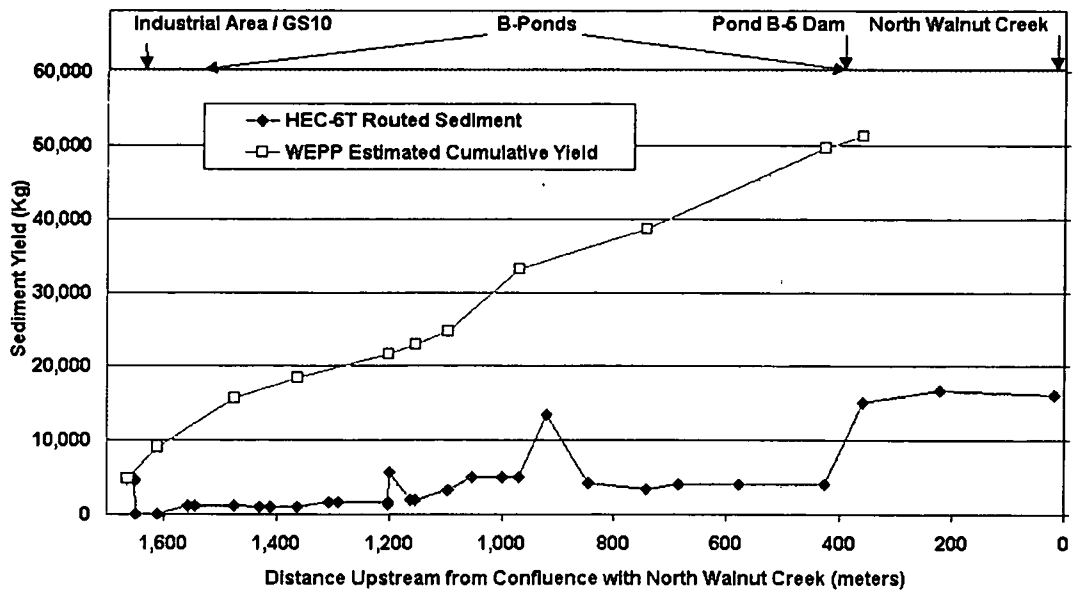
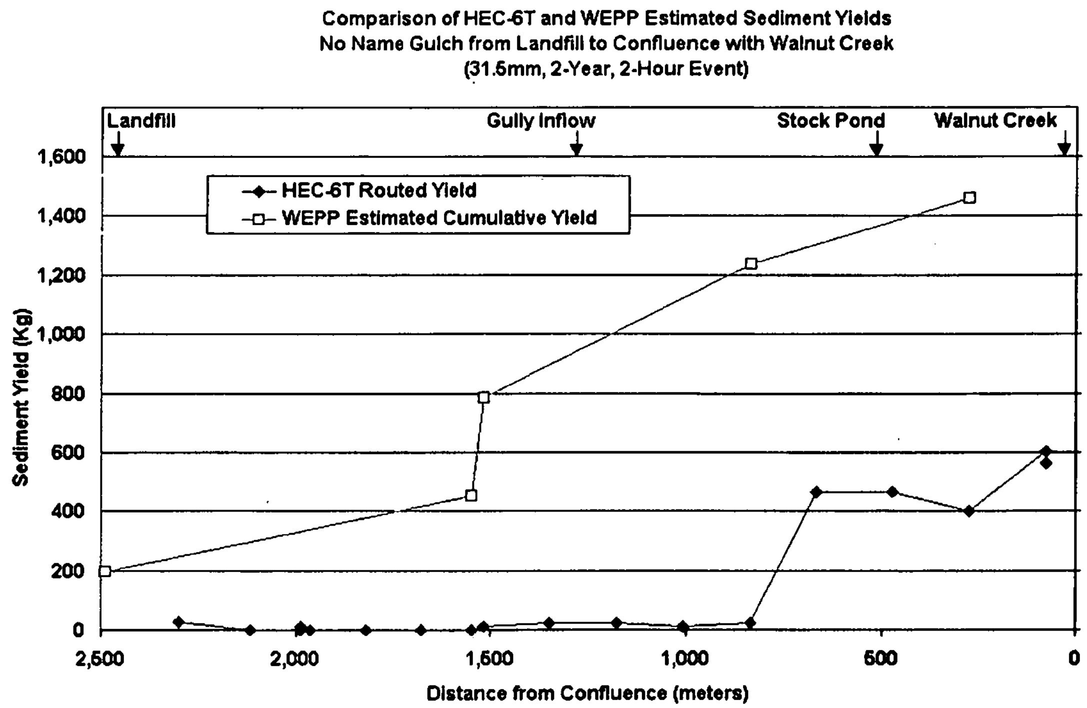


Figure C- 33. WEPP and HEC-6T Sediment Yields for No Name Gulch, 2-Year Events



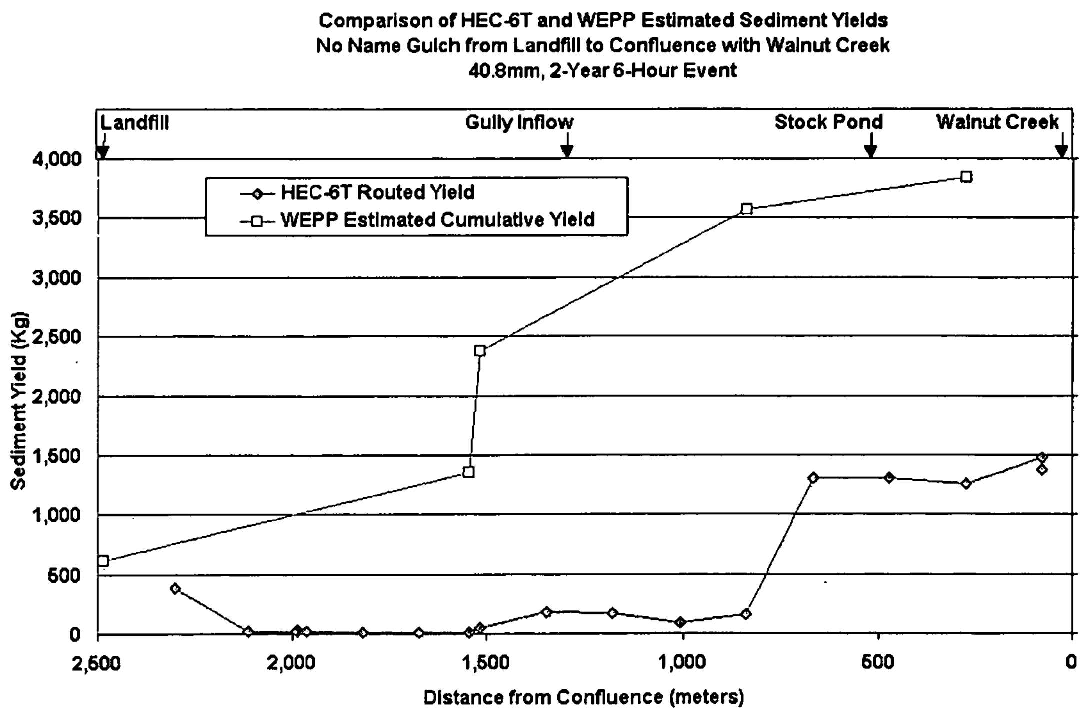


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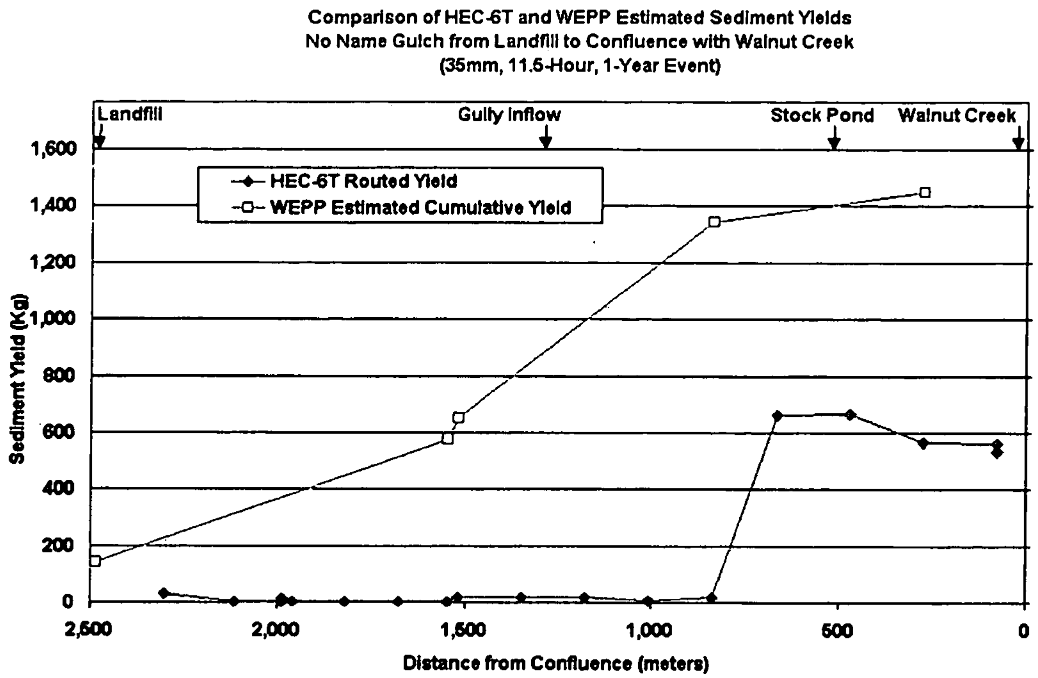
Figure C- 34. WEPP and HEC-6T Sediment Yields for No Name Gulch, 35-mm and May 17, 1995 Events



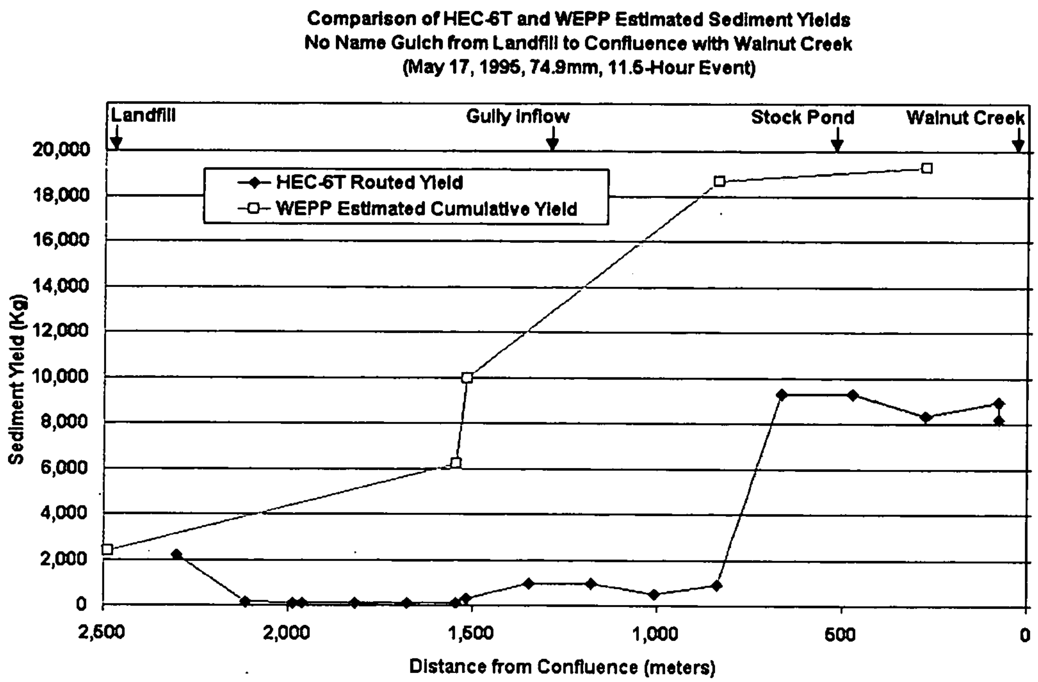


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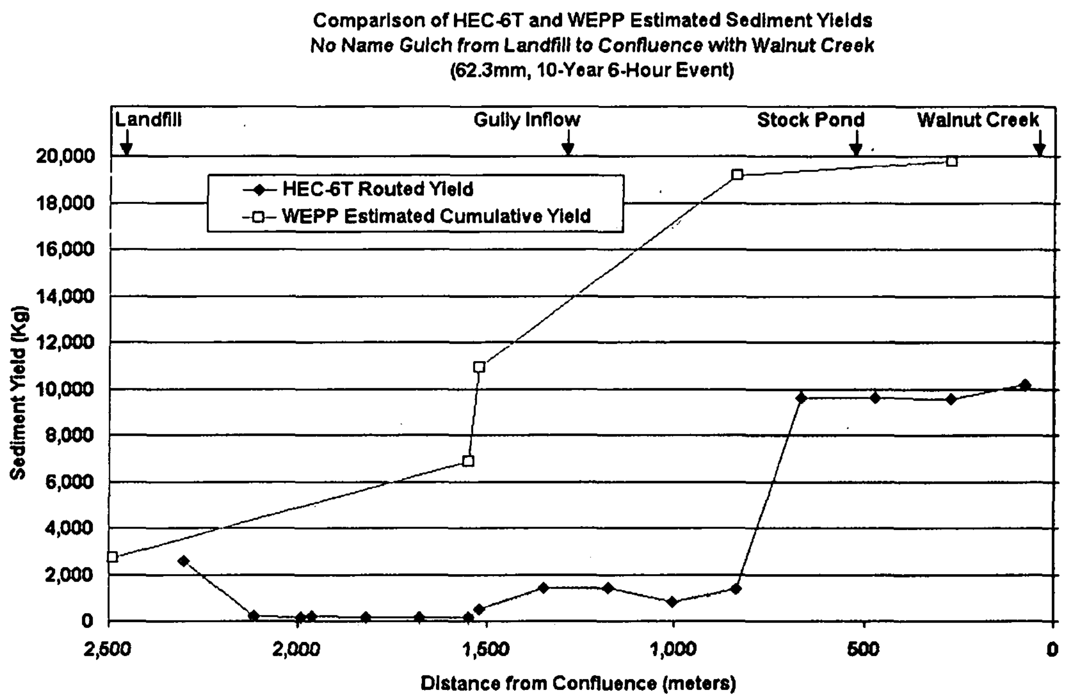
Figure C- 35. WEPP and HEC-6T Sediment Yields for No Name Gulch, 10- and 100-Year Events



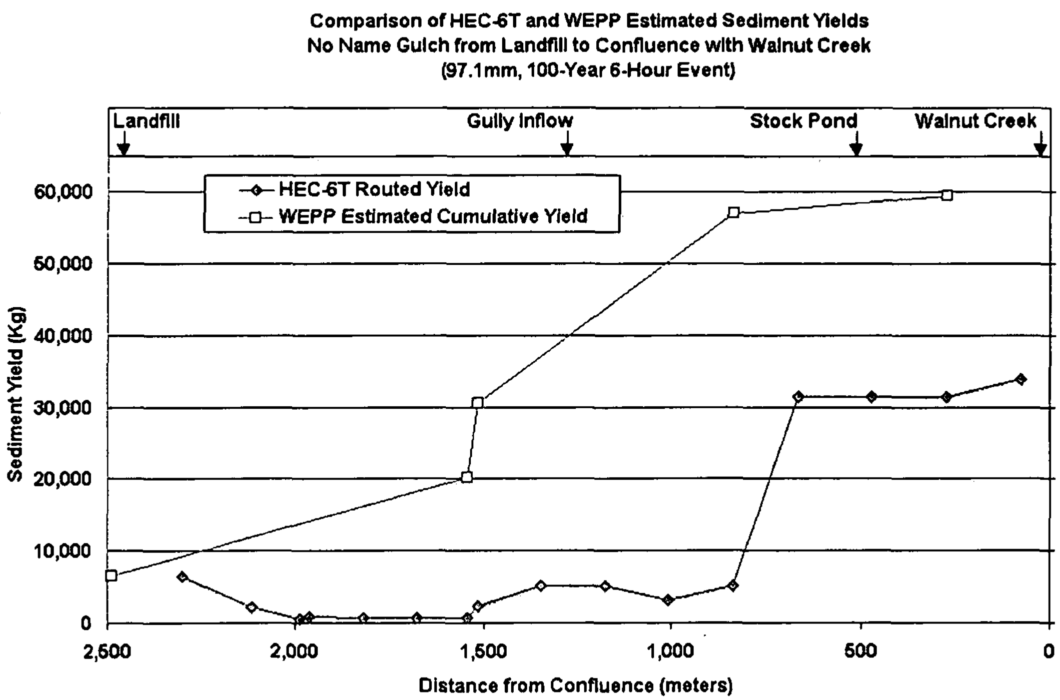


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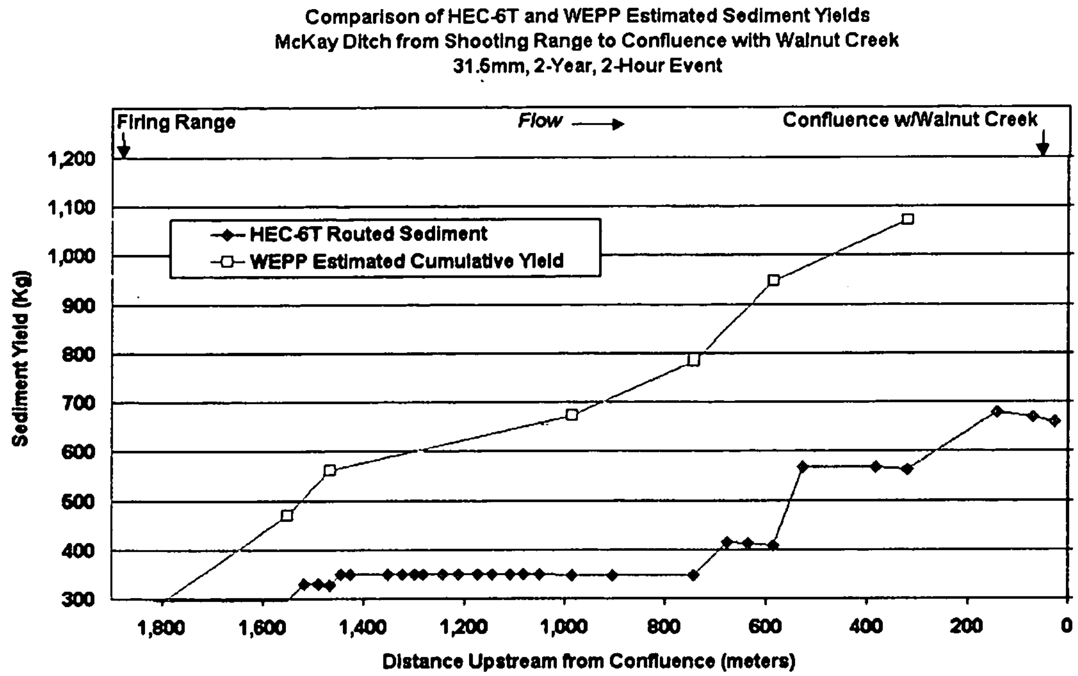
Figure C- 36. WEPP and HEC-6T Sediment Yields for McKay Ditch Bypass, 2-Year Events



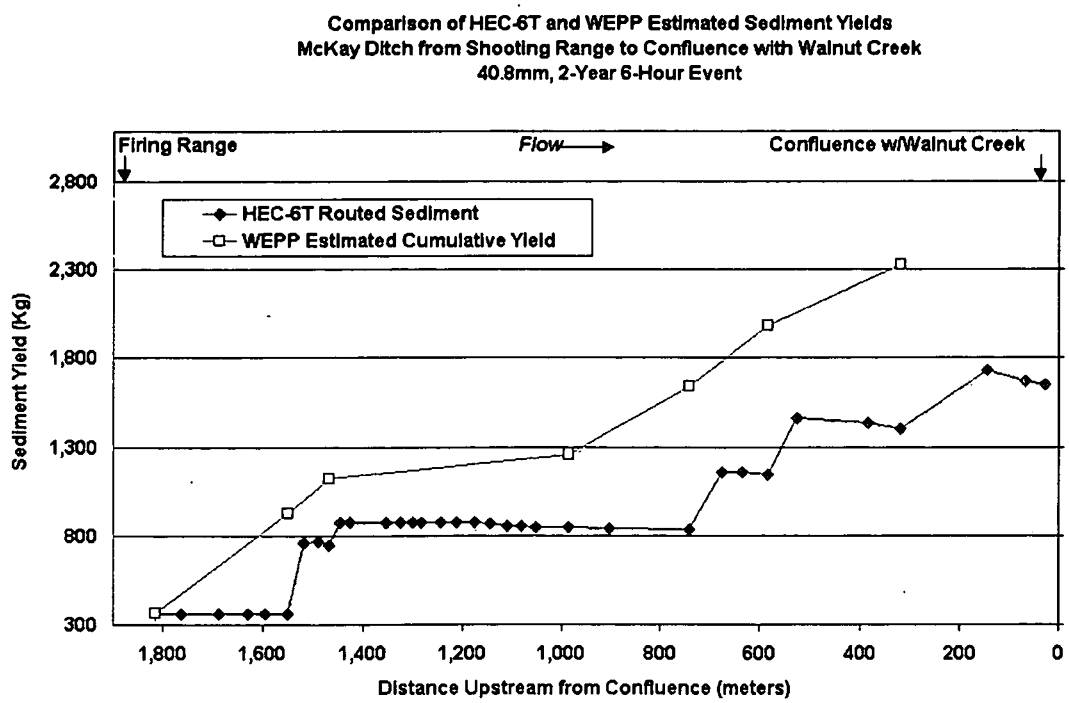
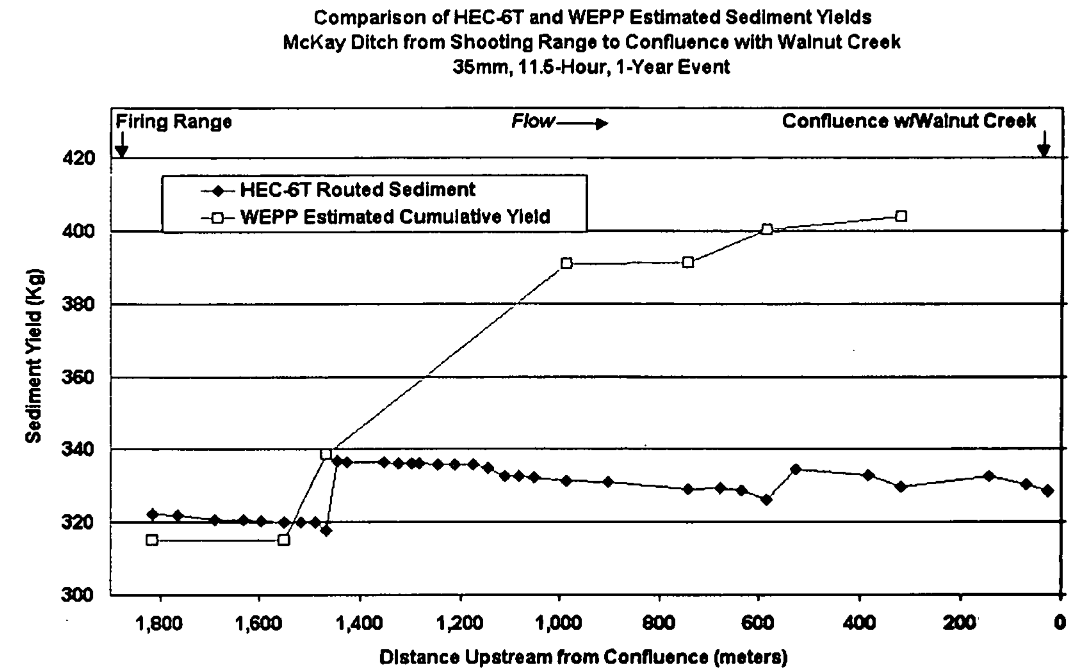


Figure C- 37. WEPP and HEC-6T Sediment Yields for McKay Ditch Bypass, 35-mm and May 17, 1995 Events



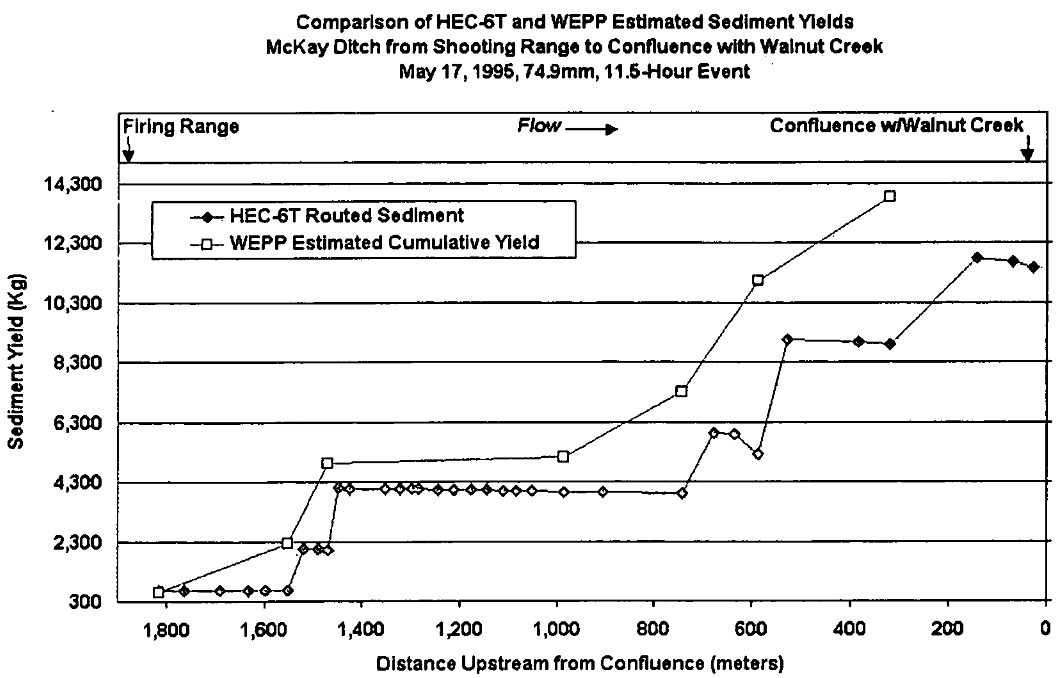


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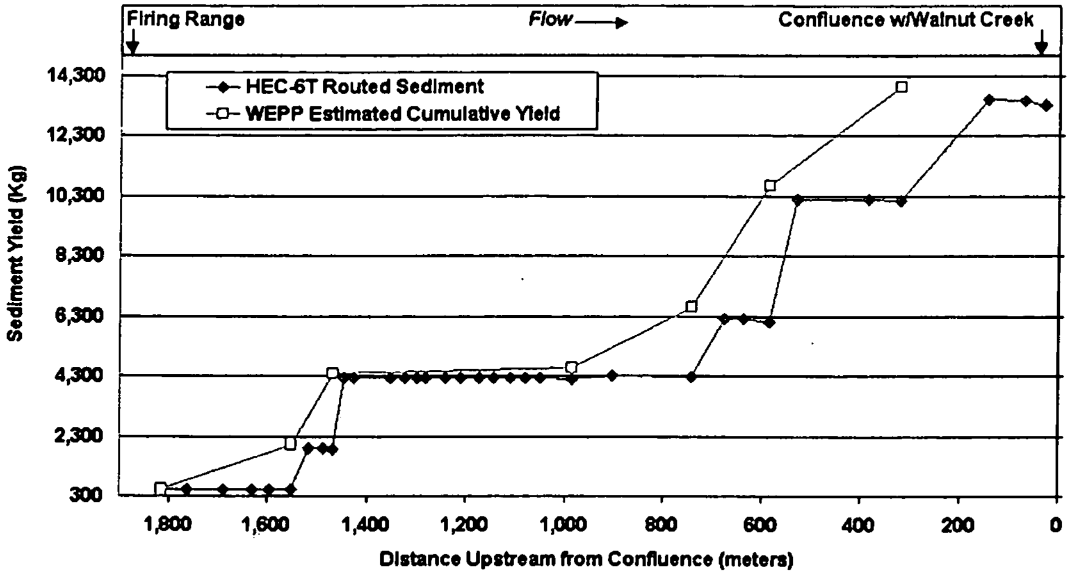
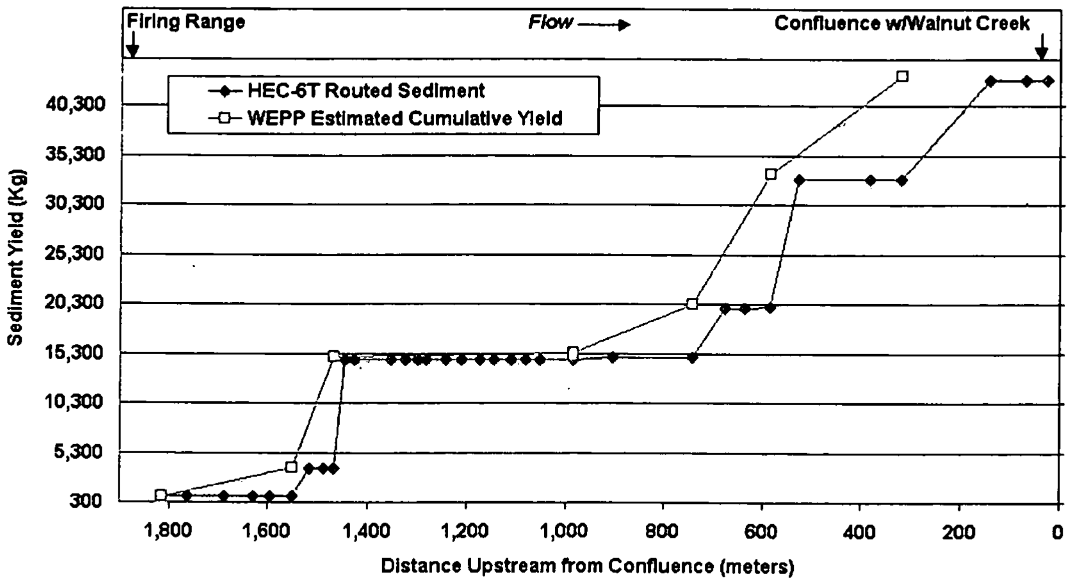
Figure C- 38. WEPP and HEC-6T Sediment Yields for McKay Ditch Bypass, 10- and 100-Year Events

Comparison of HEC-6T and WEPP Estimated Sediment Yields
McKay Ditch from Shooting Range to Confluence with Walnut Creek
62.3mm, 10-Year 6-Hour Event

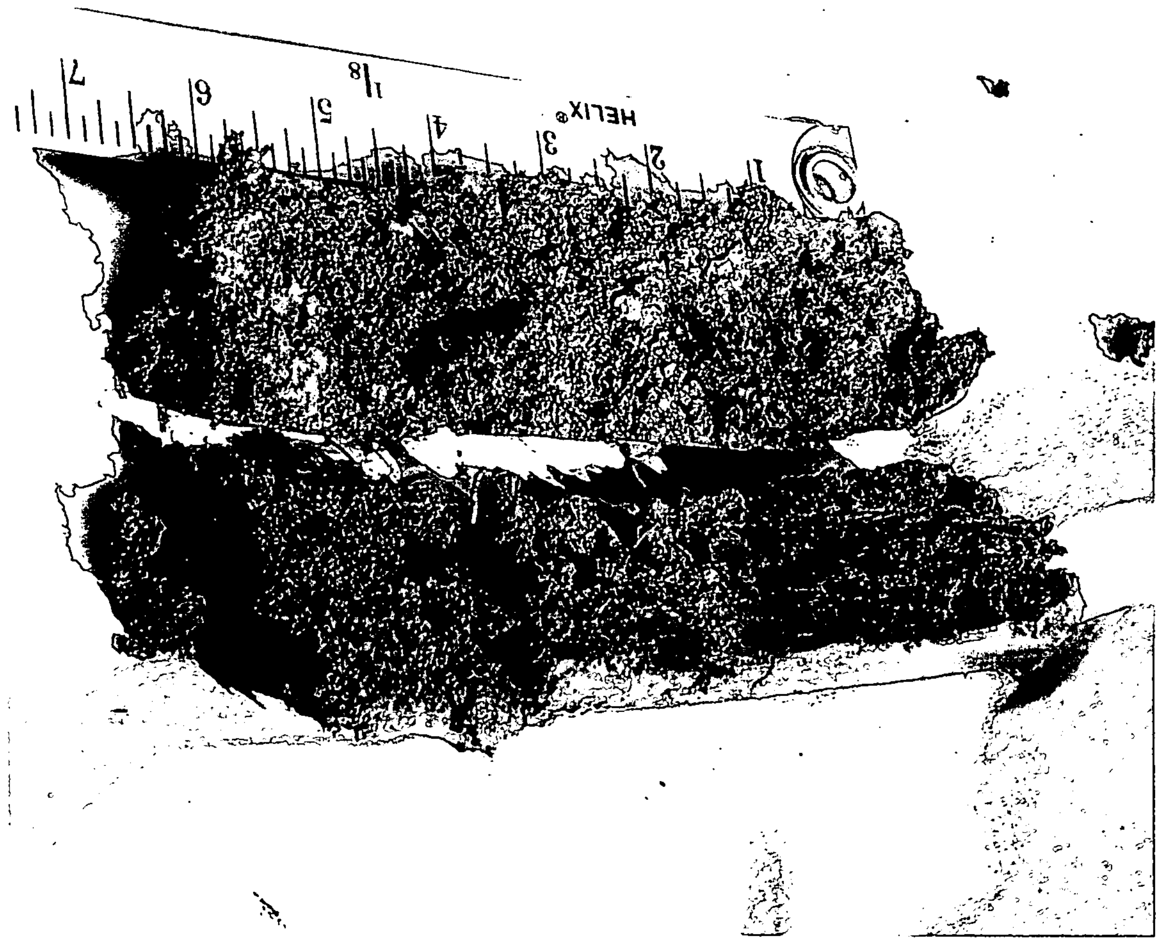


Comparison of HEC-6T and WEPP Estimated Sediment Yields
McKay Ditch from Shooting Range to Confluence with Walnut Creek
97.1mm, 100-Year 6-Hour Event



SUPPLEMENTAL INFORMATION

Appendix C - Photograph of South Interceptor Ditch Sediment Core



SID Transect Number 1
Core Description

DEPTH (INCHES)	LEFT BANK (NORTH) DESCRIPTION	DEPTH (INCHES)	CENTER DESCRIPTION	DEPTH (INCHES)	RIGHT BANK (SOUTH) DESCRIPTION
0	Sediment/water interface	0	Sediment/water interface	0	Sediment/water interface
0 - 8.0	Uniform, very fine grain dark brown with many roots, some pebbles.	0.75	Very fine grain, dark brown, vegetation / detritus, roots	1.5 - 2.0	Gray, fine grain sediment
8.0 - 12.0	Very fine grain, light brown, redish brown and black mottles -clay	0.75 - 2.5	lighter brown, large sand grains with very fine silt, roots	2.0 - 6.75	Sandy, gravely clay with roots and detritus. Pebbles to 0.5" diameter. Redish brown to yellowish brown, sandy clay.
12.0 - 12.5	Light yellow / tan clay	2.5 - 3.0	dark brown / gray silt, roots		
12.5 - 15.75	Light gray, very fine grain clay	3.0 - 5.0	light brown, very fine grain clay, roots end.		
		Top 3 inches submitted for radiochemical analysis.			
Top 8" looks depositional, some likely from bank sloughing.		**Top 3 inches appears to be depositional.**		**Top 2 inches appears to be depositional.**	

SID Transect Number 2
Core Description

DEPTH (INCHES)	LEFT BANK (NORTH) DESCRIPTION
0 - 1.5	Gravel, 0.5" diameter with clay, light brown, fine roots, some sand grains.
1.5 - 3.0	Clay with some sand, light brown
3.0 - 5.5	Less sand and more clay than previous interval, uniform light brown.
@ 5.5	Large roots and organic matter.
5.5 - 9.0	Clay with some pebbles @ 9" 3/4" rock at 9".
9.0 - 11.0	Gravel begins with clay. Gravel more frequent with depth, light brown with roots.
11.0 - 14.0	Clay with gravel, 2" rock at 14.0," light brown with roots.
14.0 - 18.0	Clay with gravel, light brown with roots.
Top 5 inches appears to be depositional.	

DEPTH (INCHES)	CENTER DESCRIPTION
0	Sediment/water interface
0 - 0.5	vegetation / detritus, gray/black vegetation / detritus, roots.
0.5 - 3.0	Gravel 0.5" diameter, sand, gray and tan.
3.0 - 5.0	Sand, high organic content, black and tan.
5.5 - 8.5	Cattail stump surrounded by black clay, blac/gray clay.
8.5 - 10.0	Gray with tan-mottled clay.
10.0 - 11.5	Light tan clay.
11.5 - 12.5	Cattail stump
12.5 - 17.0	Black and gray clay with yellow streaks.
Top 3 inches submitted for radiochemical analysis.	
Top 3 inches appears to be depositional.	

DEPTH (INCHES)	RIGHT BANK (SOUTH) DESCRIPTION
0	Sediment/water interface
0.0 - 0.5	Wet, dark brown silty/clayey organic rich sediment. Root throughout interval.
0.5 - 2.0	Clay with roots and organic matter, some sand.
2.0 - 3.0	Clay with gravel. Light brown/gray and redish brown.
3.0 - 5.0	Light brown clay with no gravel, many roots. Light gray with brown mottles.
5.0 - 12.0	5.0" - 6.0" has fine roots, few roots after 6.0". Light brown with yellow and redish/yellowish brown and gray mottles. Fine pebbles.
Top 3 inches appears to be depositional.	

SID Transect Number 3 (SW029)
Core Description

DEPTH (INCHES)	LEFT BANK (NORTH) DESCRIPTION	DEPTH (INCHES)	CENTER DESCRIPTION	DEPTH (INCHES)	RIGHT BANK (SOUTH) DESCRIPTION
0 - 3.5	Dark brown clay transitioning at 3" to 3.5" with sandy layer.	0 - 3.5	Buff/tan sediment grading to darker brown. Large sand grains in fine clay of uniform brown color.	0.0 - 4.5	Dark brown fine clay, some pebbles, and few sand grains
3.5 - 9.0	Light yellow/tan clay.			4.5 - 10.5	Lighter brown clay with dark mottles and redish brown mottles.
9 - 9.5	Gravel layer.	3.5 - 12.0	Yellowish brown fine grained clay with rocks/gravel at 9.5" - 11.0". Less sand and more clay than previous interval, uniform light brown.		
9.5 - 11.0	Light yellow/tan clay.				
Top 3.5 inches appears to be depositional.		Top 3 inches submitted for radiochemical analysis. Top 3 inches appears to be depositional.		Top 4.5 inches appears to be depositional.	

SID Transect Number 4
Core Description

DEPTH (INCHES)	LEFT BANK (NORTHEAST) DESCRIPTION	DEPTH (INCHES)	CENTER DESCRIPTION	DEPTH (INCHES)	RIGHT BANK (SOUTHWEST) DESCRIPTION
0 - 6.0	Rich brown sandy clay with light tan nodule-like concretions strewn throughout. Darker (moisture?) color at 4"	0 - 0.5	Sandy, rich, dark brown clay somewhat unconsolidated with detritus.	0.0 - 2.0	Dark brown sandy clay loam with tan concretions
		0.5 - 2.25	Same as above but consolidated, dark brown sandy clay.	2.0 - 3.5	Lighter brown sandy clay loam with tan concretions
6.0 - 8.0	More clay, no gravel, some roots. Dark brown sandy clay. At 7.5", 0.5" to 1.0" gravel starts in clay matrix.	2.25 - 5.25	Lighter brown clay with sand. Redish brown with light brown mottles and dark organic streaks. One large old root and some small roots.	3.5 - 4.0	Sand layer with large quartz sand
				4	Redish brown band (1mm thick) dividing quartz area and sandy clay loam
8.0 - 13.0	Dark brown clay with gravel of less than 1.0" diameter. A little sand and red/yellow brown mottles.				
		5.25 - 8.0	Same material as above but darker grayish brown with fine roots.	4.0 - 6.25	Sandy loam, grayish/redish brown tan mottles.
		8.0 - 11.5	Lighter brown, same as 2.25 - 5.25 with fine roots. Same sandy clay.	6.25	Dark band with light band below - Dark band = 2 mm thick, light band= 3-4 mm thick.
				6.25 - 7.5	Darker gray/brown clay with black mottles and roots, not much sand.
		Top 8 inches submitted for radiochemical analysis.		8.0 - 10.0	Lighter brown clay with fine roots and more sand than previous interval
Top 6 inches appears to be depositional.		**Top 8 inches appears to be depositional.**		10.0 - 11.0	More grayish brown clay and less sand.

Top 7.5 inches appears to be depositional.

Summary of South Interceptor Ditch Bed Sediment Investigation
for Calibration of the WEPP and HEC-6T Models

Actinide Distribution with Sediment Depth

Results are Preliminary and Subject to Revision. Radiochemistry by Sanford Cohen & Associates Southeastern Environmental Laboratory

SID Transect	Location in Sediment Column	Sample Number	Pu-239.240 (pCi/g)	Error Pu-239.240 (pCi/g)	MDA Pu-239.240 (pCi/g)	Am-241 (pCi/g)	Error Am-241 (pCi/g)	MDA Am-241 (pCi/g)	Bulk Density (g/cm^3)
1	Top	99D6166-001	0.072	0.066	0.062	0.084	0.113	0.159	NO
1	Middle	99D6166-002	0.056	0.063	0.076	0.07	0.105	0.152	-
1	Bottom	99D6166-003	0.081	0.08	0.091	-0.005	0.097	0.175	SAMPLE
2	Top	99D6166-004	0.084	0.071	0.061	0.1	0.126	0.173	NO
2	Middle	99D6166-005	0.008	0.03	0.066	-0.067	0.108	0.216	-
2	Bottom	99D6166-006	0.109	0.087	0.042	0.031	0.105	0.171	SAMPLE
3	Top	99D6166-007	0.982	0.339	0.042	0.284	0.156	0.128	1.198
3	Middle	99D6166-008	0.72	0.269	0.084	0.226	0.14	0.126	1.247
3	Bottom	99D6166-009	0.601	0.233	0.08	0.136	0.11	0.121	1.144
4	Top	99D6166-010	0.386	0.177	0.04	0.083	0.092	0.12	1.361
4	Middle	99D6166-011	0.149	0.104	0.089	0.016	0.065	0.115	1.524
4	Bottom	99D6166-012	0.807	0.299	0.077	-0.01	0.059	0.126	1.207

Notes: 1) Radiochemical results are consistently above the minimum detectable activity in transects 3 & 4.
2) Validation of rad data in progress as of 5/17/99

ROCKY FLATS DRAINAGE AND FLOOD CONTROL MASTER PLAN
6-HOUR DURATION DESIGN STORMS

TIME (MIN)	2-YR (IN)	5-YR (IN)	10-YR (IN)	25-YR (IN)	50-YR (IN)	100-YR (IN)
5	0.02	0.029	0.037	0.031	0.031	0.026
10	0.042	0.053	0.061	0.072	0.083	0.081
15	0.092	0.13	0.137	0.112	0.118	0.122
20	0.172	0.219	0.257	0.172	0.189	0.212
25	0.262	0.36	0.437	0.322	0.359	0.38
30	0.152	0.187	0.213	0.527	0.589	0.672
35	0.068	0.082	0.102	0.242	0.289	0.38
40	0.052	0.063	0.082	0.167	0.189	0.212
45	0.031	0.052	0.072	0.107	0.118	0.168
50	0.031	0.052	0.062	0.107	0.118	0.132
55	0.031	0.044	0.062	0.067	0.079	0.108
60	0.031	0.044	0.062	0.065	0.079	0.108
65	0.031	0.044	0.062	0.065	0.079	0.108
70	0.02	0.044	0.037	0.052	0.076	0.052
75	0.02	0.037	0.037	0.052	0.057	0.052
80	0.02	0.032	0.031	0.042	0.043	0.032
85	0.02	0.032	0.028	0.038	0.043	0.032
90	0.02	0.032	0.028	0.032	0.033	0.032
95	0.02	0.032	0.028	0.032	0.033	0.032
100	0.02	0.023	0.028	0.032	0.033	0.032
105	0.02	0.023	0.028	0.032	0.033	0.032
110	0.02	0.023	0.028	0.032	0.033	0.032
115	0.02	0.023	0.026	0.032	0.033	0.032
120	0.02	0.02	0.023	0.028	0.033	0.032
125	0.014	0.012	0.011	0.012	0.013	0.015
130	0.014	0.012	0.011	0.012	0.013	0.015
135	0.009	0.008	0.011	0.012	0.013	0.015
140	0.009	0.008	0.011	0.012	0.013	0.015
145	0.009	0.008	0.011	0.012	0.013	0.015
150	0.009	0.008	0.011	0.012	0.013	0.015
155	0.009	0.008	0.011	0.012	0.013	0.015
160	0.009	0.008	0.011	0.012	0.013	0.015
165	0.009	0.008	0.011	0.012	0.013	0.015
170	0.009	0.008	0.011	0.012	0.013	0.015
175	0.009	0.008	0.011	0.012	0.013	0.015
180	0.009	0.008	0.011	0.012	0.013	0.015
185	0.009	0.008	0.011	0.012	0.013	0.015
190	0.007	0.006	0.011	0.012	0.013	0.015
195	0.007	0.006	0.011	0.012	0.013	0.015
200	0.007	0.006	0.011	0.012	0.013	0.015
205	0.007	0.006	0.011	0.012	0.013	0.015
210	0.007	0.006	0.011	0.012	0.013	0.015
215	0.007	0.006	0.011	0.012	0.013	0.015
220	0.007	0.006	0.011	0.012	0.013	0.015
225	0.007	0.006	0.011	0.012	0.013	0.015
230	0.007	0.006	0.011	0.012	0.013	0.015
235	0.007	0.006	0.011	0.012	0.013	0.015
240	0.007	0.006	0.011	0.012	0.013	0.015
245	0.007	0.006	0.011	0.012	0.013	0.015
250	0.007	0.006	0.011	0.012	0.013	0.015
255	0.007	0.006	0.011	0.012	0.013	0.015
260	0.007	0.006	0.011	0.012	0.013	0.015
265	0.007	0.006	0.011	0.012	0.013	0.015
270	0.007	0.006	0.011	0.012	0.013	0.015
275	0.007	0.006	0.011	0.012	0.013	0.015
280	0.007	0.006	0.011	0.012	0.013	0.015
285	0.007	0.006	0.011	0.012	0.013	0.015
290	0.007	0.006	0.011	0.012	0.013	0.015
295	0.007	0.006	0.008	0.012	0.013	0.015
300	0.007	0.006	0.008	0.01	0.013	0.015
305	0.007	0.006	0.008	0.01	0.013	0.015
310	0.007	0.006	0.008	0.01	0.013	0.015
315	0.007	0.006	0.008	0.01	0.013	0.015
320	0.007	0.006	0.008	0.01	0.013	0.015
325	0.007	0.006	0.008	0.01	0.013	0.015
330	0.007	0.006	0.008	0.01	0.013	0.015
335	0.007	0.006	0.008	0.01	0.013	0.015
340	0.007	0.006	0.008	0.01	0.013	0.015
345	0.007	0.006	0.008	0.01	0.013	0.015
350	0.007	0.006	0.008	0.01	0.013	0.015
355	0.007	0.006	0.008	0.01	0.013	0.015
360	0.007	0.006	0.008	0.01	0.013	0.015
TOTALS:	1.6	2.0	2.5	3.0	3.4	3.8

ESTIMATION OF GULLY EROSION FROM ROUTING CENTRAL AVENUE DITCH FLOOD WATERS TO SOUTH WALNUT CREEK ABOVE POND B-5.

FIELD DATA COLLECTED 7/16/99 BY G. WETHERBEE AND P. DEARCOS

DISTANCE BETWEEN SECTIONS (FEET)	CUMMULATIVE CHANNEL LENGTH (FEET)	CHANNEL WIDTH (FEET)	CHANNEL DEPTH (FEET)	VOLUME[1] OF ERODED SEDIMENT (CUBIC FEET)
39	39	11	1	215
11	50	11	6	363
8	58	11	9	396
6	64	16.5	6	297
14	78	11	3.5	270
41	119	11.5	6	1,415
65	184	10	8	2,600
73	257	22	8	6,424
39	296	13	7.5	1,901
33	329	13	6	1,287
29	358	8	4	464
63	421	8	7	1,764
51	472	22	15	8,415
58	530	13	8	3,016
61	591	18	10	5,490
73	664	13	8	3,796
98	762	15	7	5,145
105	867	8	8	3,360
97	964	9.5	9	4,147
103	1067	15	11	8,498
30	1097	2	2	60
TOTAL SEDIMENT (CUBIC FEET):				59,321
TOTAL SEDIMENT (CUBIC METERS):				1,680
[2] TOTAL MASS OF MATERIAL ERODED (Metric Tons):				3,360
UNIT EROSION (Metric Tons/Meter of Channel Length):				10

NOTES: 1) Volume determined by assuming triangular channel.
2) Mass determined by assuming density of 2 g/cc.
3) East Central Avenue gully erosion estimated at 1,400 Tons based on Unit Erosion given above and 140 meter channel length.

388 c:\901-004\830gaw\gully.xls wwe 9/30/99 des. by: gaw ckd by: lfs

WALNUT CREEK - INDUSTRIAL AREA HYDROLOGY

(Source: Rocky Flats Drainage and Flood Control Master Plan (EG&G, 1992))

Master Plan Sub-Basin ID	Sub-Basin Area (Acres)	Peak Q										ACRE-FEET				
		2-yr	CFS/AC	10-yr	CFS/AC	25-yr	CFS/AC	50-yr	CFS/AC	100-yr	CFS/AC	2-yr	10-yr	25-yr	50-yr	100-yr
CSWAA	115	74	0.643478	130	1.130435	190	1.652174	220	1.913043	260	2.26087	11	18	22	25	29
CSWAB	109	87	0.798165	160	1.46789	230	2.110092	270	2.477064	320	2.93578	10	17	21	24	27
CWAB	11	9	0.818182	15	1.363636	22	2	27	2.454545	34	3.090909	1	1	2	2	2
CWAC	117	86	0.735043	170	1.452991	250	2.136752	300	2.564103	350	2.991453	9	15	20	23	26
CWAA	15	11	0.733333	25	1.666667	35	2.333333	42	2.8	50	3.333333	1	2	2	2	3
CSWAA + CSWAB	224	161	0.71875	290	1.294643	420	1.875	490	2.1875	580	2.589286	21	35	43	49	56
CWADIV 1	20	24	1.2	41	2.05	54	2.7	63	3.15	72	3.6	2	3	4	5	5
CWADIV 2	29	39	1.344828	66	2.275862	87	3	100	3.448276	120	4.137931	3	5	7	8	9
CWADIV 1 + 2	49	63	1.285714	107	2.183673	141	2.877551	163	3.326531	192	3.918367	5	8	11	13	14
CWAC SUB-BASINS																
CWAC 8	10			SOLAR PONDS, NO RUNOFF												
CWAC 2&5	28	21		41		60		72		84						
CWAA1 & CWAC 1,3,4,6,7,9,10,11,12,13	125	92		182		268		322		375						

HILLSLOPE	INFLOW DESCRIPTION
91	NORTH IA RUNOFF TO SW093
92	SOUTH IA RUNOFF TO GS10
93	WEST / 130 AREA RUNOFF TO MCKAY BYPASS
77	SOLAR PONDS

Appendix C, Water-Stable Aggregate Particle Size Distributions for Site Soils and Sediments

Particle Size Distribution Data for Fractionated Soil and Sediment Samples.
Data provided by Colorado School of Mines, 1998

Sample Location	Hillslope Position of Sample	Fraction Passing Sieve by Weight			
		> 200 μm	< 200 μm	< 10 μm	< 2 μm
SSSE01498	Toeslope	0.2770	0.6550	0.0480	0.0200
SSSE01498	Toeslope	0.3990	0.5450	0.0430	0.0130
SSSE05798	Toeslope	0.4640	0.4900	0.0280	0.0180
SSSE05798	Toeslope	0.5090	0.4460	0.0280	0.0170
SSSE05698	Toeslope	0.5470	0.3930	0.0430	0.0170
SSSE02198	Toeslope	0.5900	0.3760	0.0190	0.0150
SSSE01198	Sideslope	0.1960	0.6890	0.0860	0.0290
SSSE01398	Sideslope	0.5120	0.4400	0.0370	0.0110
SSSE05498	Sideslope	0.5160	0.4260	0.0360	0.0220
SSSE05598	Sideslope	0.5330	0.4360	0.0200	0.0110
SSSE05198	Topslope	0.3740	0.5930	0.0190	0.0140
SSSE05198	Topslope	0.4470	0.5300	0.0170	0.0060
SSSE00598	Topslope	0.4540	0.5180	0.0100	0.0180
SSSE05398	Topslope	0.4620	0.4950	0.0250	0.0180
SSSE05298	Topslope	0.5040	0.4460	0.0300	0.0200
SSSE00698	Topslope	0.5170	0.4440	0.0290	0.0100
SSSE00798	Topslope	0.5420	0.4240	0.0230	0.0110
SSSE00498	Topslope	0.6340	0.3430	0.0160	0.0070
15697	Sediment	0.1380	0.7150	0.1080	0.0390
16797	Sediment	0.3500	0.5720	0.0500	0.0280
16297	Sediment	0.3660	0.5960	0.0270	0.0110
		> 200 μm	< 200 μm	< 10 μm	< 2 μm
	Mean Values for Topslope Soils:	**0.4918**	**0.4741**	**0.0211**	**0.0130**
	Standard Deviation:	0.0772	0.0765	0.0069	0.0053
	Mean Values for Sideslope Soils:	**0.4393**	**0.4978**	**0.0448**	**0.0183**
	Standard Deviation:	0.1624	0.1276	0.0286	0.0088
	Mean Values for Toeslope Soils:	**0.4643**	**0.4842**	**0.0348**	**0.0167**
	Standard Deviation:	0.1131	0.1043	0.0114	0.0024
	Mean Values for All Soils:	**0.4709**	**0.4827**	**0.0309**	**0.0154**
	Standard Deviation:	0.1064	0.0926	0.0172	0.0057
	Mean Values for Stream Sediments:	**0.2847**	**0.6277**	**0.0617**	**0.0260**
	Standard Deviation:	0.1273	0.0766	0.0417	0.0141

SUMMARY OF WEPP-ESTIMATED SPECIFIC GRAVITY AND PARTICLE SIZE DISTRIBUTIONS FOR SUSPENDED SEDIMENTS IN EACH WATERSHED

WATERSHED	SPECIFIC GRAVITY (g/cm^3)		
	SAND	SILT	CLAY
SOUTH INTERCEPTOR DITCH	2.10	1.66	2.60
WOMAN CREEK	2.17	1.77	2.60
WALNUT CREEK	2.87	2.57	2.60

WATERSHED	PARTICLE SIZE DISTRIBUTION (PERCENT)		
	SAND	SILT	CLAY
SOUTH INTERCEPTOR DITCH	82.0	14.0	4.0
WOMAN CREEK	71.2	23.3	5.5
WALNUT CREEK	77.0	19.0	4.0

PEBBLE COUNT SURVEY

Stream Name: Woman Creek　　　Plot Number: W-2

Time: 　　　Date: 2/2/99

SIZE RANGE (millimeters)	CLASS NAME	TOTAL NUMBER	TOTAL PERCENT	CUMULATIVE NUMBER	CUMULATIVE PERCENT
<25.4	Sm. Organic	0			
>25.4	Lg. Organic	0			
<.0039	Clay	0	0.00	0	0
.0039-.0625	Silt	0	0.00	0	0
.0625-.25	Fine Sand	0	0.00	0	0
.25-.50	Med. Sand	2	0.02	2	0.02
.50-1.0	Course Sand	0	0.00	2	0.02
1.0-2.0	V. Course Sand	0	0.00	2	0.02
2.0-4.0	V. Fine Gravel	0	0.00	2	0.02
4.0-6.0	Fine Gravel	0	0.00	2	0.02
6.0-8.0	Fine Gravel	9	0.09	11	0.11
8.0-16.0	Med. Gravel	16	0.16	27	0.27
16.0-32.0	Course Gravel	27	0.27	54	0.54
32.0-64.0	V. Course Gravel	20	0.20	74	0.74
64.0-128.0	Small Cobble	19	0.19	93	0.93
128.0-256.0	Large Cobble	7	0.07	100	1
256.0-512.0	Small Boulder	0	0.00	100	1
512.0-1024.0	Medium Boulder	0	0.00	100	1
1024.0-2049.0	Large Boulder	0	0.00	100	1
2049.0-4096.0	V. Large Boulder	0	0.00	100	1
	Bedrock	0	0.00	100	1
TOTAL		100	1.00	100	1

Survey Comments:

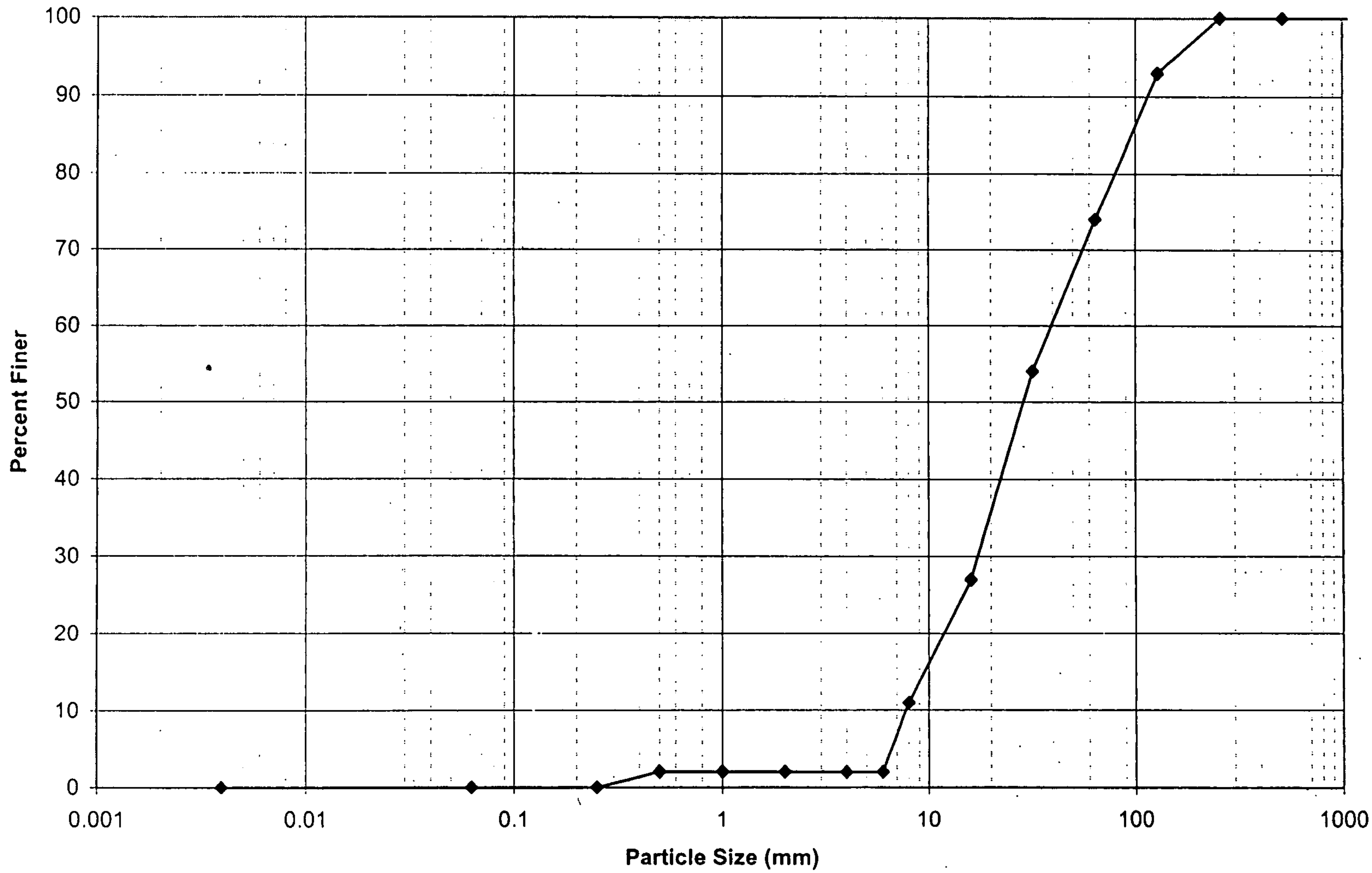
General Site Observations:

Photographs: Yes No　　　Video: Yes No

Scientist Signature:

Crowley & Rouse

Woman Creek Pebble Count (47+99)
RMRS Sediment Transport



392 RFETS-Sediment Transport
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PEBBLE COUNT SURVEY

Stream Name: South Upper Woman Plot Number: SUW-4

Time: ______ Date: 3/25/99

SIZE RANGE (millimeters)	CLASS NAME	TOTAL NUMBER	TOTAL PERCENT	CUMULATIVE NUMBER	CUMULATIVE PERCENT
<25.4	Sm. Organic	0			
>25.4	Lg. Organic	0			
<.0039	Clay	4	0.04	4	0.04040404
.0039-.0625	Silt	23	0.23	27	0.272727273
.0625-.25	Fine Sand	4	0.04	31	0.313131313
.25-.50	Med. Sand	4	0.04	35	0.353535354
.50-1.0	Course Sand	3	0.03	38	0.383838384
1.0-2.0	V. Course Sand	2	0.02	40	0.404040404
2.0-4.0	V. Fine Gravel	1	0.01	41	0.414141414
4.0-6.0	Fine Gravel	1	0.01	42	0.424242424
6.0-8.0	Fine Gravel	5	0.05	47	0.474747475
8.0-16.0	Med. Gravel	5	0.05	52	0.525252525
16.0-32.0	Course Gravel	11	0.11	63	0.636363636
32.0-64.0	V. Course Gravel	9	0.09	72	0.727272727
64.0-128.0	Small Cobble	11	0.11	83	0.838383838
128.0-256.0	Large Cobble	13	0.13	96	0.96969697
256.0-512.0	Small Boulder	3	0.03	99	1
512.0-1024.0	Medium Boulder	0	0.00	99	1
1024.0-2049.0	Large Boulder	0	0.00	99	1
2049.0-4096.0	V. Large Boulder	0	0.00	99	1
	Bedrock	0	0.00	99	1
TOTAL		99	1.00	99	1

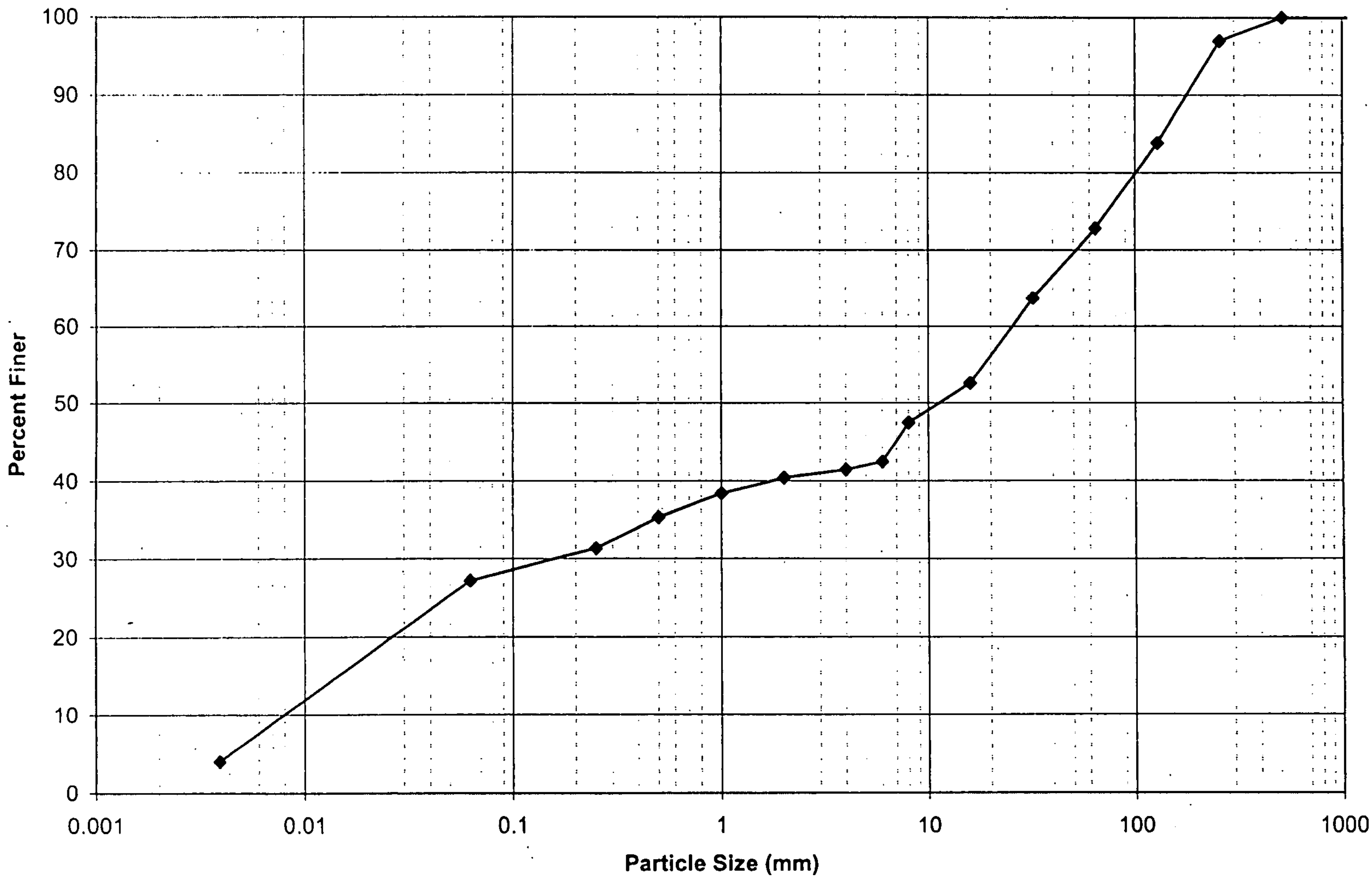
Survey Comments:

General Site Observations: Use this bed gradation for North Upper Woman also.

Photographs: Yes No Video: Yes No

Scientist Signature: Wetherbee & Schaper

South Upper Woman Pebble Count (16+43)
RMRS Sediment Transport



PEBBLE COUNT SURVEY

Stream Name: Smart Ditch

Plot Number: S-6

Time:

Date: 2/2/99

SIZE RANGE (millimeters)	CLASS NAME	TOTAL NUMBER	TOTAL PERCENT	CUMULATIVE NUMBER	CUMULATIVE PERCENT
<25.4	Sm. Organic	0			
>25.4	Lg. Organic	0			
<.0039	Clay	0	0.00	0	0
.0039-.0625	Silt	0	0.00	0	0
.0625-.25	Fine Sand	0	0.00	0	0
.25-.50	Med. Sand	0	0.00	0	0
.50-1.0	Course Sand	0	0.00	0	0
1.0-2.0	V. Course Sand	0	0.00	0	0
2.0-4.0	V. Fine Gravel	0	0.00	0	0
4.0-6.0	Fine Gravel	0	0.00	0	0
6.0-8.0	Fine Gravel	7	0.07	7	0.07
8.0-16.0	Med. Gravel	8	0.08	15	0.15
16.0-32.0	Course Gravel	14	0.14	29	0.29
32.0-64.0	V. Course Gravel	17	0.17	46	0.46
64.0-128.0	Small Cobble	42	0.42	88	0.88
128.0-256.0	Large Cobble	12	0.12	100	1
256.0-512.0	Small Boulder	0	0.00	100	1
512.0-1024.0	Medium Boulder	0	0.00	100	1
1024.0-2049.0	Large Boulder	0	0.00	100	1
2049.0-4096.0	V. Large Boulder	0	0.00	100	1
	Bedrock	0	0.00	100	1
TOTAL		100	1.00	100	1

Survey Comments:

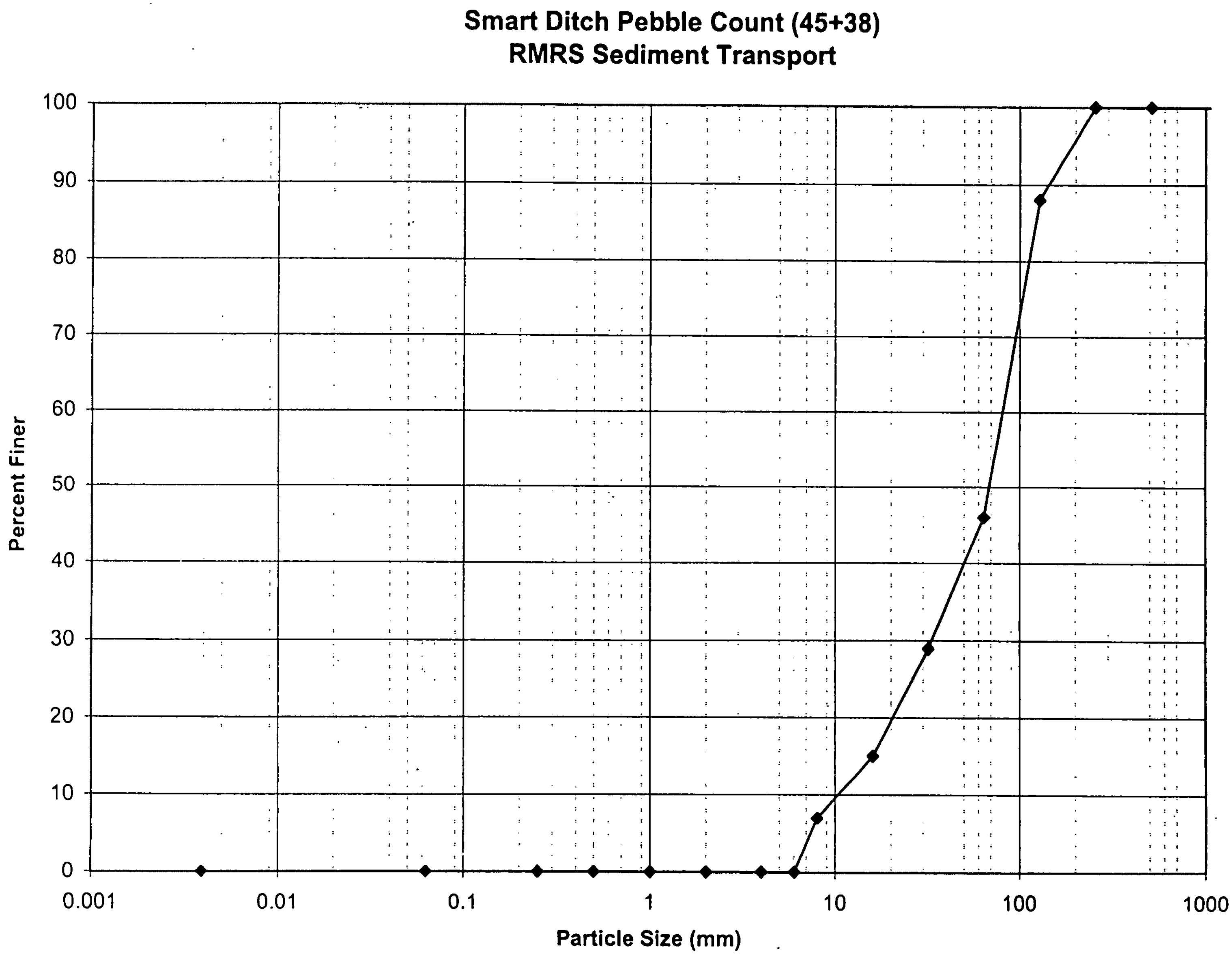
General Site Observations:

Photographs: Yes No

Video: Yes No

Scientist Signature:

Crowley & Rouse



346 RFETS-Sediment Transport
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PEBBLE COUNT SURVEY

Stream Name: Mower Ditch

Plot Number: mw-4

Time:

Date: February 2, 1999

SIZE RANGE (millimeters)	CLASS NAME	TOTAL NUMBER	TOTAL PERCENT	CUMULATIVE NUMBER	CUMULATIVE PERCENT
<25.4	Sm. Organic				
>25.4	Lg. Organic				
<.0039	Clay	0	0	0	0
.0039-.0625	Silt	0	0	0	0
.0625-.25	Fine Sand	0	0	0	0
.25-.50	Med. Sand	9	0.09	9	0.09
.50-1.0	Course Sand	0	0	9	0.09
1.0-2.0	V. Course Sand	0	0	9	0.09
2.0-4.0	V. Fine Gravel	0	0	9	0.09
4.0-6.0	Fine Gravel	0	0	9	0.09
6.0-8.0	Fine Gravel	1	0.01	10	0.1
8.0-16.0	Med. Gravel	6	0.06	16	0.16
16.0-32.0	Course Gravel	20	0.2	36	0.36
32.0-64.0	V. Course Gravel	12	0.12	48	0.48
64.0-128.0	Small Cobble	44	0.44	92	0.92
128.0-256.0	Large Cobble	8	0.08	100	1
256.0-512.0	Small Boulder	0	0	100	1
512.0-1024.0	Medium Boulder	0	0	100	1
1024.0-2049.0	Large Boulder	0	0	100	1
2049.0-4096.0	V. Large Boulder	0	0	100	1
	Bedrock	0	0	100	1
TOTAL		100	1	100	1

Survey Comments:

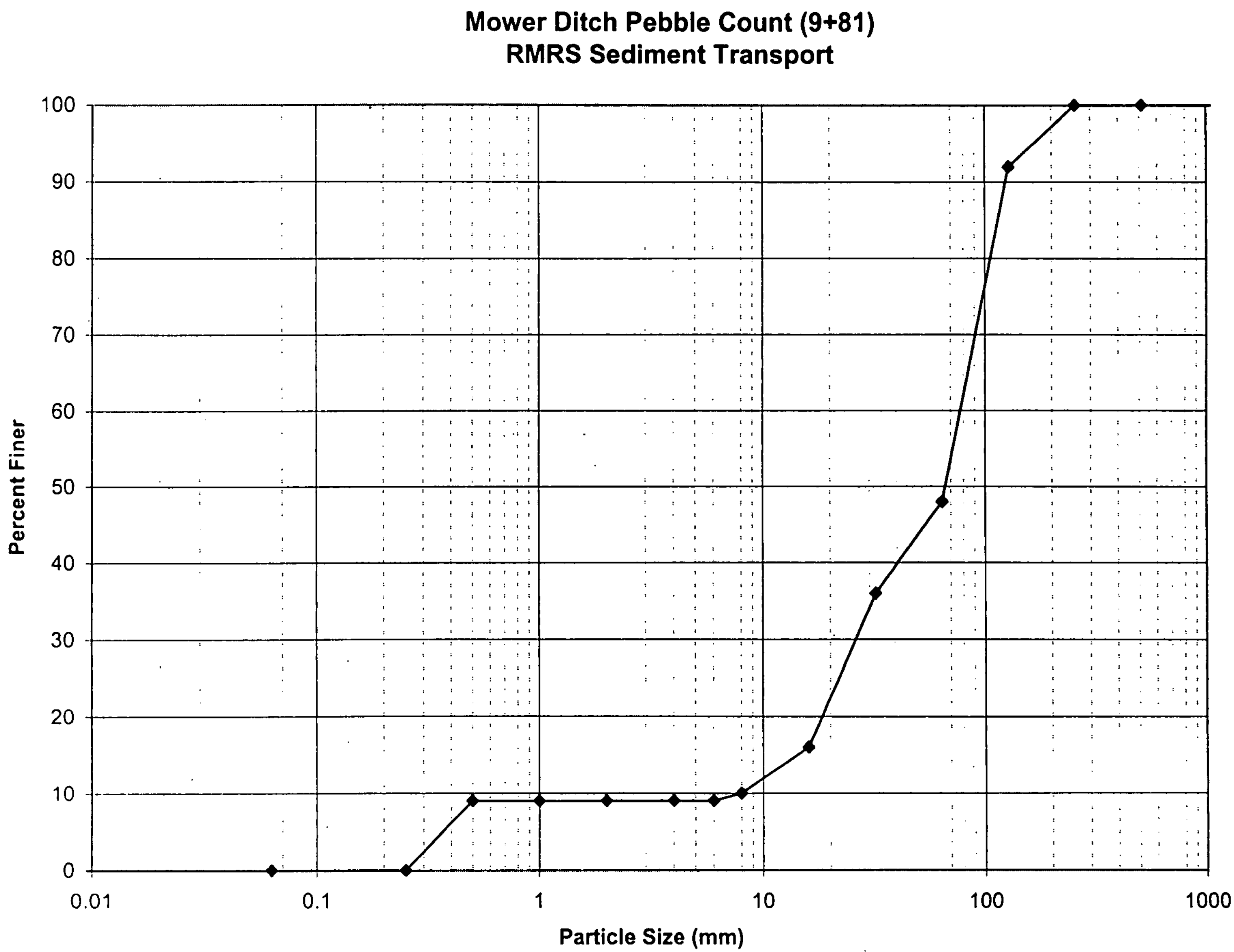
General Site Observations:

Photographs: Yes No

Video: Yes No

Scientist Signature:

Chris Crowly & JP Rouse



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PEBBLE COUNT SURVEY

Stream Name: North Walnut Creek

Plot Number: NWA-3

Time: 12:43 p.m.

Date: February 9, 1999

SIZE RANGE (millimeters)	CLASS NAME	TOTAL NUMBER	TOTAL PERCENT	CUMULATIVE NUMBER	CUMULATIVE PERCENT
<25.4	Sm. Organic				
>25.4	Lg. Organic				
<.0039	Clay	10	0.10	10	0.1
.0039-.0625	Silt	0	0.00	10	0.1
.0625-.25	Fine Sand	0	0.00	10	0.1
.25-.50	Med. Sand	10	0.10	20	0.2
.50-1.0	Course Sand	0	0.00	20	0.2
1.0-2.0	V. Course Sand	0	0.00	20	0.2
2.0-4.0	V. Fine Gravel	0	0.00	20	0.2
4.0-6.0	Fine Gravel	5	0.05	25	0.25
6.0-8.0	Fine Gravel	5	0.05	30	0.3
8.0-16.0	Med. Gravel	0	0.00	30	0.3
16.0-32.0	Course Gravel	0	0.00	30	0.3
32.0-64.0	V. Course Gravel	20	0.20	50	0.5
64.0-128.0	Small Cobble	50	0.50	100	1
128.0-256.0	Large Cobble	0	0.00	100	1
256.0-512.0	Small Boulder	0	0.00	100	1
512.0-1024.0	Medium Boulder	0	0.00	100	1
1024.0-2049.0	Large Boulder	0	0.00	100	1
2049.0-4096.0	V. Large Boulder	0	0.00	100	1
	Bedrock	0	0.00	100	1
TOTAL		100	1.00	100	1

Survey Comments: Tall, thick willows on banks

General Site Observations:

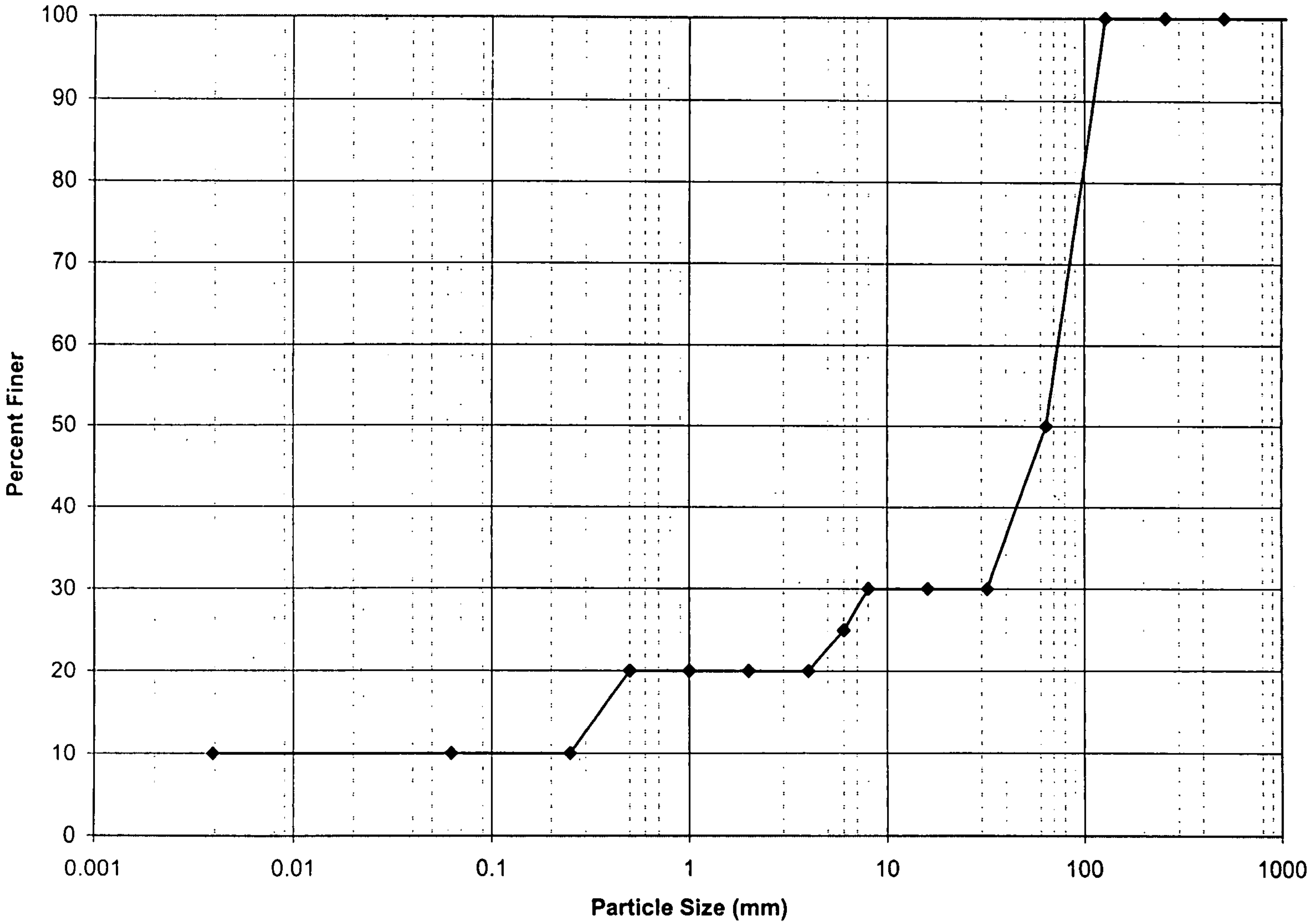
Photographs: Yes No

Video: Yes No

Scientist Signature: [signature]

Greg Wetherbee

North Walnut Creek Pebble Count (64+10)
RMRS Sediment Transport



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PEBBLE COUNT SURVEY

Stream Name: McKay Ditch

Plot Number: MK-4

Time: 8:45 a.m.

Date: February 9, 1999

SIZE RANGE (millimeters)	CLASS NAME	TOTAL NUMBER	TOTAL PERCENT	CUMULATIVE NUMBER	CUMULATIVE PERCENT
<25.4	Sm. Organic				
>25.4	Lg. Organic				
<.0039	Clay	0	0.00	0	0
.0039-.0625	Silt	0	0.00	0	0
.0625-.25	Fine Sand	0	0.00	0	0
.25-.50	Med. Sand	0	0.00	0	0
.50-1.0	Course Sand	0	0.00	0	0
1.0-2.0	V. Course Sand	0	0.00	0	0
2.0-4.0	V. Fine Gravel	0	0.00	0	0
4.0-6.0	Fine Gravel	0	0.00	0	0
6.0-8.0	Fine Gravel	0	0.00	0	0
8.0-16.0	Med. Gravel	0	0.00	0	0
16.0-32.0	Course Gravel	0	0.00	0	0
32.0-64.0	V. Course Gravel	0	0.00	0	0
64.0-128.0	Small Cobble	0	0.00	0	0
128.0-256.0	Large Cobble	0	0.00	0	0
256.0-512.0	Small Boulder	50	0.50	50	0.5
512.0-1024.0	Medium Boulder	50	0.50	100	1
1024.0-2049.0	Large Boulder	0	0.00	100	1
2049.0-4096.0	V. Large Boulder	0	0.00	100	1
	Bedrock	0	0.00	100	1
TOTAL		100	1.00	100	1

Survey Comments: Riprap Lined Channel

General Site Observations: Clumps of 5-8 year-old cottonwood trees (12 ft tall) along banks 5-6" diameter. No flow in the channel at this day. Main use is bypass of irrigation water thru site.

Photographs: Yes No

Video: Yes No

Scientist Signature:

Greg Wetherbee

RFETS
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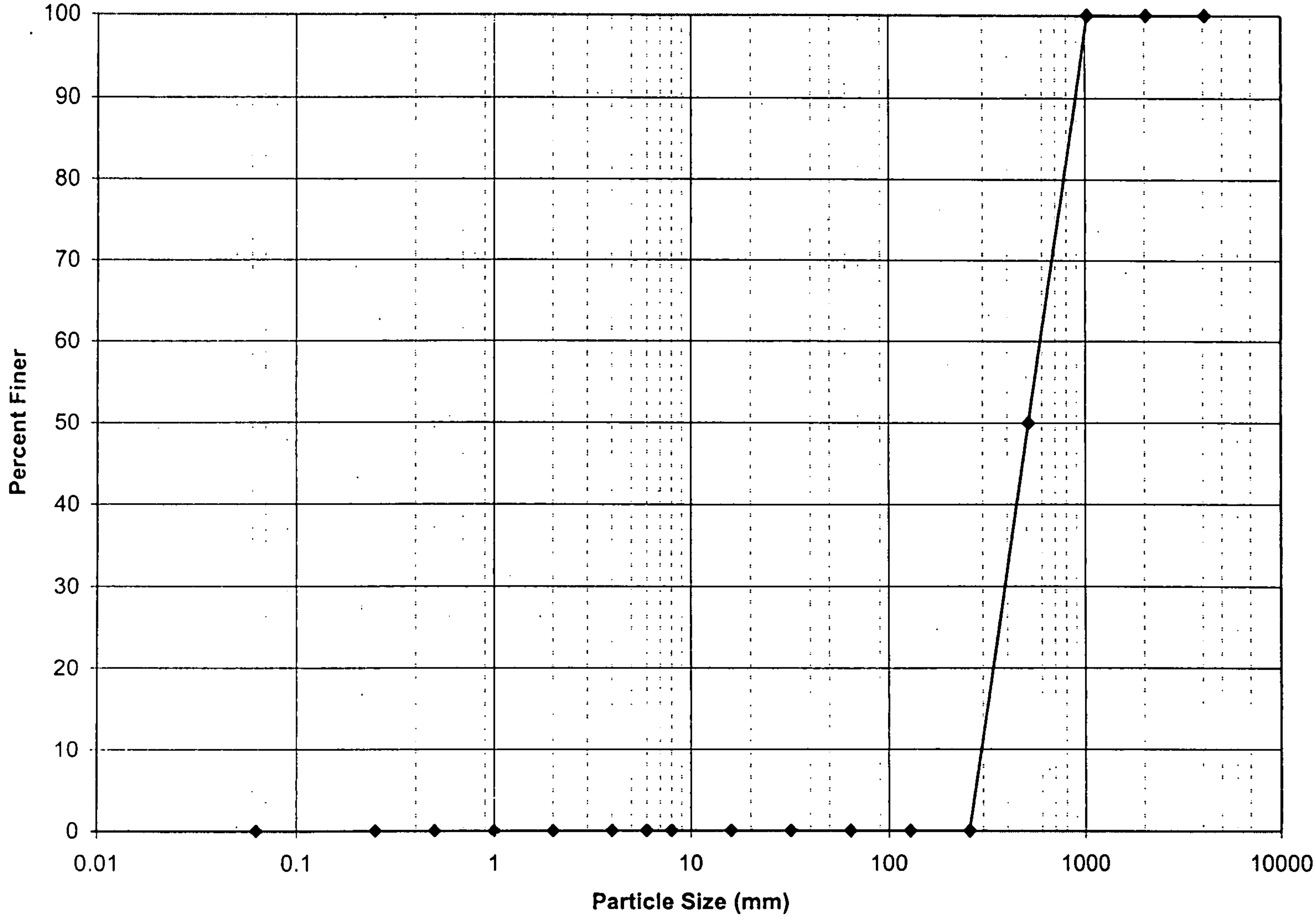
McKay Ditch Pebble Count (29+63)
RMRS Sediment Transport



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PEBBLE COUNT SURVEY

Stream Name: Walnut Creek | Plot Number: WA-5
Time: 13:01 p.m. | Date: February 2, 1999

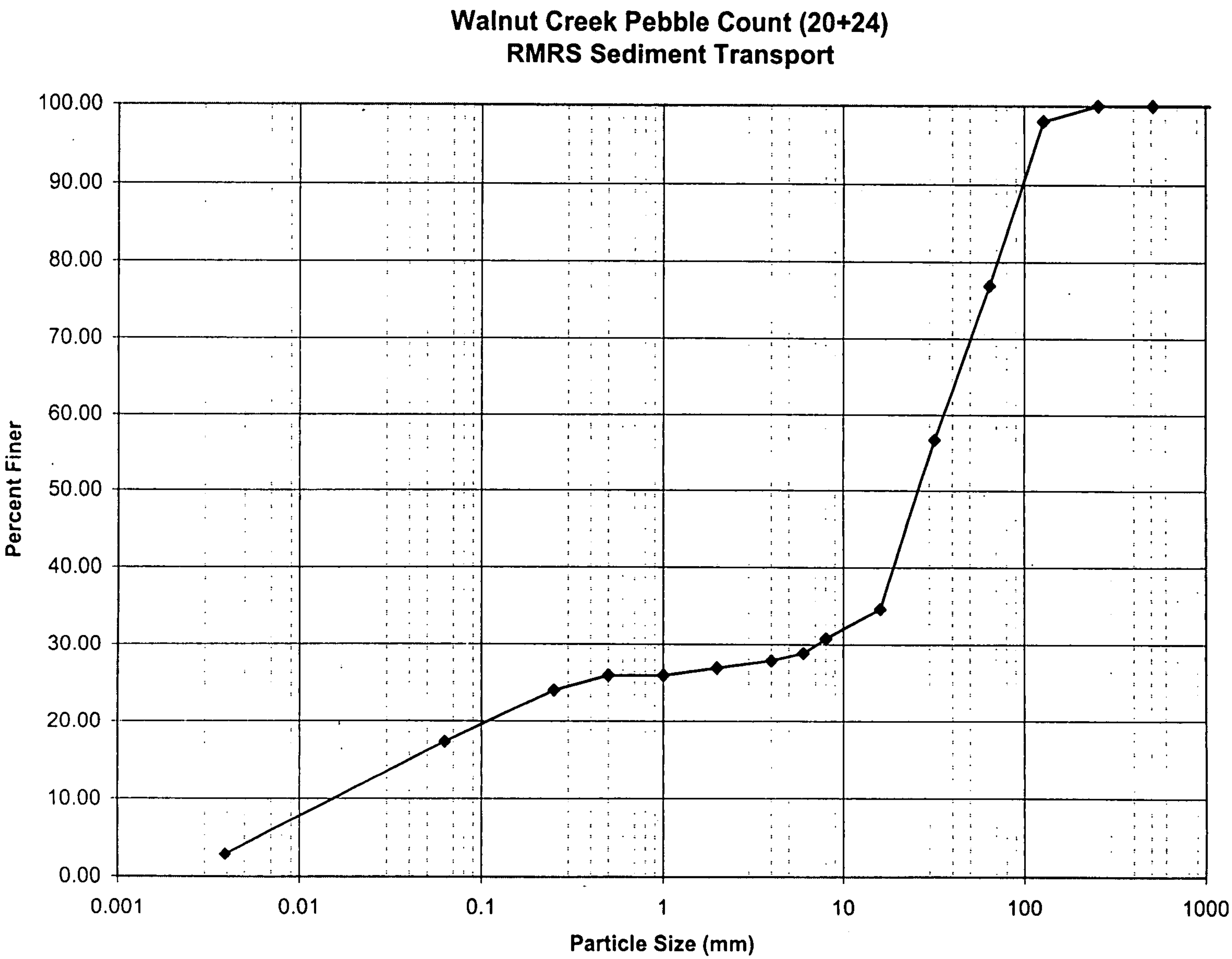
SIZE RANGE (milimeters)	CLASS NAME	TOTAL NUMBER	TOTAL PERCENT	CUMULATIVE NUMBER	CUMULATIVE PERCENT
<25.4	Sm. Organic				
>25.4	Lg. Organic				
<.0039	Clay	3	0.03	3	0.028846154
.0039-.0625	Silt	15	0.14	18	0.173076923
.0625-.25	Fine Sand	7	0.07	25	0.240384615
.25-.50	Med. Sand	2	0.02	27	0.259615385
.50-1.0	Course Sand	0	0.00	27	0.259615385
1.0-2.0	V. Course Sand	1	0.01	28	0.269230769
2.0-4.0	V. Fine Gravel	1	0.01	29	0.278846154
4.0-6.0	Fine Gravel	1	0.01	30	0.288461538
6.0-8.0	Fine Gravel	2	0.02	32	0.307692308
8.0-16.0	Med. Gravel	4	0.04	36	0.346153846
16.0-32.0	Course Gravel	23	0.22	59	0.567307692
32.0-64.0	V. Course Gravel	21	0.20	80	0.769230769
64.0-128.0	Small Cobble	22	0.21	102	0.980769231
128.0-256.0	Large Cobble	2	0.02	104	1
256.0-512.0	Small Boulder	0	0.00	104	1
512.0-1024.0	Medium Boulder	0	0.00	104	1
1024.0-2049.0	Large Boulder	0	0.00	104	1
2049.0-4096.0	V. Large Boulder	0	0.00	104	1
	Bedrock	0	0.00	104	1
TOTAL		104	1.00	104	1

Survey Comments: Tall, thick willows on banks

General Site Observations:

Photographs: Yes No | Video: Yes No

Scientist Signature: Greg Wetherbee



404 RFETS-Sediment Transport
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PEBBLE COUNT SURVEY

Stream Name: South Walnut Creek — Plot Number: SWA-6

Time: 13:38 p.m. — Date: February 9, 1999

SIZE RANGE (millimeters)	CLASS NAME	TOTAL NUMBER	TOTAL PERCENT	CUMULATIVE NUMBER	CUMULATIVE PERCENT
<25.4	Sm. Organic				
>25.4	Lg. Organic				
<.0039	Clay	35	0.35	35	0.35
.0039-.0625	Silt	35	0.35	70	0.7
.0625-.25	Fine Sand	0	0.00	70	0.7
.25-.50	Med. Sand	10	0.10	80	0.8
.50-1.0	Course Sand	0	0.00	80	0.8
1.0-2.0	V. Course Sand	0	0.00	80	0.8
2.0-4.0	V. Fine Gravel	0	0.00	80	0.8
4.0-6.0	Fine Gravel	0	0.00	80	0.8
6.0-8.0	Fine Gravel	5	0.05	85	0.85
8.0-16.0	Med. Gravel	5	0.05	90	0.9
16.0-32.0	Course Gravel	5	0.05	95	0.95
32.0-64.0	V. Course Gravel	5	0.05	100	1
64.0-128.0	Small Cobble	0	0.00	100	1
128.0-256.0	Large Cobble	0	0.00	100	1
256.0-512.0	Small Boulder	0	0.00	100	1
512.0-1024.0	Medium Boulder	0	0.00	100	1
1024.0-2049.0	Large Boulder	0	0.00	100	1
2049.0-4096.0	V. Large Boulder	0	0.00	100	1
	Bedrock	0	0.00	100	1
TOTAL		100	1.00	100	1

Survey Comments: Tall, thick willows on banks

General Site Observations:

Photographs: Yes No — Video: Yes No

Scientist Signature: Greg Wetherbee

RFETS-Sediment Transport — Wright Water Engineers, Inc. — des by lfs

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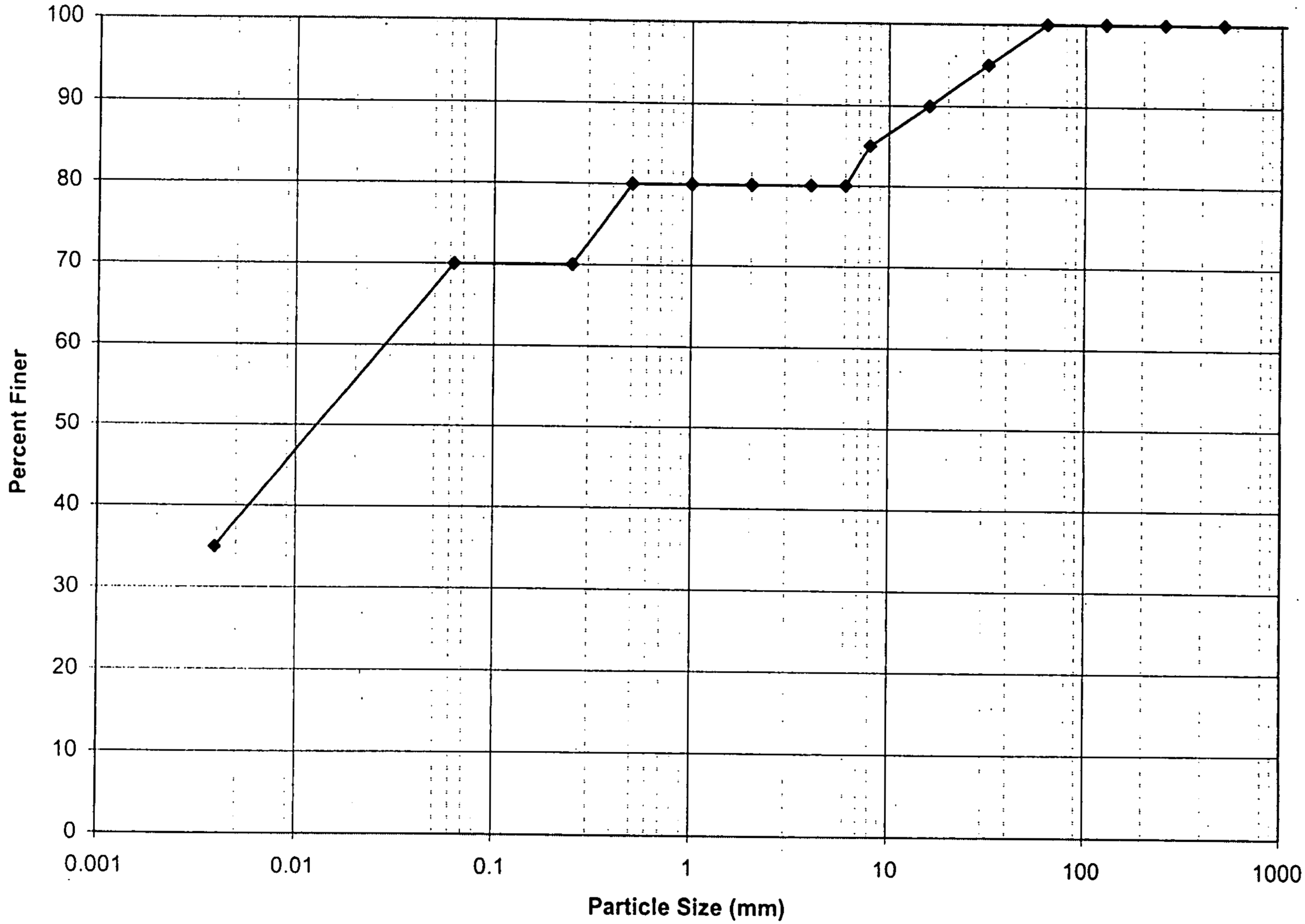
South Walnut Creek Pebble Count (31+86)
RMRS Sediment Transport



406 RFETS-Sediment Transport
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APPENDIX D

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D.1 Introduction

Computer models rely on an underlying conceptual model of a physical process or set of processes, mathematical algorithms that attempt to replicate these processes, and input data or measurements. Each of these items contains a degree of uncertainty, which, to varying degrees, affect the overall quality and uncertainty of the model estimates.

The Actinide Migration Evaluation (AME) team used four primary modeling techniques in combination to quantify the physical movement of actinides in surface soils by water. They are geostatistical modeling (Kriging), geographic information systems (GIS), process-based erosion modeling using the Water Erosion Prediction Project (WEPP) model, and stream sedimentation modeling using the Sedimentation in Stream Networks (HEC-6T) model. The objective in using multiple models was to provide the best estimate of the impact of actinide soil contamination on surface water quality, which is a function of multiple processes and inputs.

The inputs to the models, such as precipitation, temperature, and watershed characteristics subject to statistical sampling, are random variables; thus, all model outputs are random variables and embody various levels of uncertainty. There must be sufficient confidence that the model is able to accurately simulate and quantify erosion and deposition from those same processes that have resulted in the present conditions at the Site. To assess the overall quality of the model, it is important to understand the nature of the uncertainties, their relative or quantified magnitudes, their impacts on the models, and how the impacts are mitigated and minimized during the modeling processes. This appendix discusses both general and specific aspects in model quality assessment for each type of primary model as well as presents the final model results derived through integration of the four primary models.

D.1.1 Sources of Uncertainty

Model output uncertainty can be attributed to three general sources: (1) structural uncertainty; (2) input uncertainty; and (3) parameter uncertainty. Structural uncertainty relates to the degree to which the model accurately and completely represents the physical system under analysis. Input uncertainty reflects the spatial and temporal variability of the input data along with measurement errors. Parameter uncertainty refers to the uncertainty associated with internal model parameters, which are fixed and not usually adjusted or available for adjustment by the user. These three categories of uncertainty are discussed in the following subsections.

D.1.2 Structural Uncertainty

Computer models start with a conceptual model of how a natural system works and how the various components interrelate. This conceptual model, generally developed by experts in the system to be modeled, is then transformed into computer algorithms, which attempt to replicate the structure of the natural systems as accurately as possible.

Physical systems are typically highly complex and often contain components that are not completely understood or measurable. Any model of the system must make simplifying assumptions in order to reduce the level of complexity, account for knowledge gaps, and to offer a solution that is feasible given available technology and computer power while maintaining structural integrity.

For any given modeling task, more than one computer-based model is commonly available for application. This is the case for the primary models (geostatistical techniques, GIS, WEPP, and HEC-6T) of the AME, where multiple modeling techniques are available for each of the primary models used. The various modeling options available for each of the primary modeling tasks (spatial modeling, geographic analysis, erosion modeling, and sediment transport modeling) were evaluated to determine the most appropriate and applicable modeling technique for the desired overall project objectives.

Each of the models selected met several selection criteria, the first of which was structural integrity and completeness. In addition, the models fulfilled other criteria including that they (1) represent a state-of-the-art/industry standard technique; (2) be well documented; (3) be technically feasible; (4) be subject to verification by independent parties; and (5) be cost-effective in the project time frame. Key attributes of each of the primary models are discussed below.

D.1.2.1 Spatial Modeling

Geostatistical modeling techniques were selected as the method to assess the spatial distribution of actinide concentrations in the Rocky Flats Environmental Technology Site (RFETS or Site) soils. Geostatistical techniques, including variograms and kriging, are a form of spatial analysis often applied to the contouring of sample data. Many computer-based contouring algorithms are available but do not possess the structural adequacy and completeness of the geostatistical approach (David, 1977).

Several structural components of geostatistical modeling contributed to the selection of this approach. First, geostatistics is a proven technique that has been widely and successfully

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applied in many sciences and industries, including the environmental field (Myers, 1997). Second, the geostatistical model is able to provide a custom characterization of the spatial distribution of site contamination. This customization function cannot be performed by other methods and provides a more accurate model since every site is unique. Third, kriging is a minimum error estimator, providing "best" estimates (unbiased and lowest possible error) of contaminant concentrations, thereby affording a high degree of confidence to the overall model. Next, kriging is able to quantify the levels of estimation error, an attribute not available in other contouring approaches. Finally, geostatistical techniques have been previously applied at the RFETS, which provides a basis of comparison for new studies.

D.1.2.2 Geographic Information Systems

GIS techniques were selected because they combine the power of relational database information with sophisticated spatial analysis. Computerized databases provide a time-tested approach to data management. When databases are linked to advanced spatial analytical and mapping tools through GIS, an unparalleled level of power and flexibility for spatial analysis is created. In addition, GIS tools offer any efficient computer-based approach that can perform tasks more quickly than other methods, while maintaining structural integrity and completeness.

D.1.2.3 Erosion Modeling

The United States Department of Agriculture (USDA) initiated the WEPP model in 1985. The USDA's mission in developing WEPP was "to develop new generation water erosion prediction technology for use...in soil and water conservation and environmental planning and assessment" (Foster and Lane, 1987). The computer model for WEPP is based on fundamentals of infiltration, surface runoff, plant growth, residue decomposition, hydraulics, tillage, management, soil consolidation, and erosion mechanics. Process-based erosion models such as WEPP provide major advantages over empirically based erosion prediction technology. The model has been extensively tested and validated in a variety of environments. A complete description of WEPP appears in the main body of this report.

D.1.2.4 Channel Flow Modeling

The HEC-6T model is an updated version of the established and validated channel flow family of HEC models. The recently updated version employed by the AME team contains modifications that better simulate the flow in small streams, such as those found at the RFETS.

A summary of the structural characteristics of the primary models appears in Table D-1.

Table D- 1. Structural Components: Primary Models

PRIMARY MODEL	ATTRIBUTE				
	Accuracy	Completeness	Appropriateness/ Applicability	Efficiency/ Speed	Comments
Geostatistics	High	High	Excellent	Excellent	USEPA-supported; customized analysis to reflect unique site conditions
GIS	High	High	Excellent	Excellent to Fair (for customized hillslope applications)	State-of-the-art technology
WEPP	Very Good	High	Excellent	Excellent	Most applicable for hillslopes
HEC-6T	Good	High	Good	Excellent	Originally designed for large rivers but now adapted to small streams

Note: Attributes for models are not quantitative and are only indicative of relative quality/performance.

D.1.2.4.1 Submodel Issues

Each of the primary models contains other types of models (submodels) that are used to perform specific subportions of the primary model. Submodels have benefits and limitations in their structures that are analogous to the structural completeness of the primary models. Table D-2 summarizes the structural issues relating to the major submodels.

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Table D- 2. Structural Analysis: Submodels

PRIMARY MODEL	SUBMODEL	ATTRIBUTES	UNCERTAINTY ISSUES	SENSITIVITY TO SIMPLIFYING ASSUMPTIONS
Geostatistics	Variogram	Maximizes informational value of sample data	Relies on professional judgment	Relatively low
	Kriging	Minimizes estimation error and bias	Incorporates limited professional judgment	Relatively low
	Estimation Error	Quantifies spatial uncertainty	NA	NA
GIS	Hillslope Design	Simplifies topographic attributes	Contour interval; relies on professional judgment	Low to moderate
	TIN Surface	Incorporates spatial data	Has a smoothing effect	Relatively low
WEPP	Vegetation Cover and Growth	100-year plant growth simulations contain some anomalous values	Professional judgment used in addition to data; relies on calibration to account for anomalies	Low to moderate
	Soil Type	Simplifies variations in regional soils. Soil variability sufficiently large that soils were grouped by position on landscape.	Boundaries tend to be gradational, not sharp; soil infiltration rate and percent saturation highly influence results; calibrated to observed stream-flow rather than measured infiltration rates	Low to moderate
WEPP (cont.)	Sediment Particle Size/Aggregation	Particle aggregation is texture dependent in model.	Tends to produce large aggregates in sediment delivered to surface water	Moderate
	Climate / Rainfall Simulator	Incorporates regional and/or local data	Statistical robustness of synthetic climate data depends on quality and length of period of record for measured data.	Low
	Hillslope Hydraulics	Has high impact on runoff and erosion	Relies on calibration of the model (Risse, 1994); sensitive to hillslope length (scale)	Moderate to high
	Soil Erodibility-Interrill and Rill Factors	Empirically derived from rain simulation study	Rill factor sensitive to hillslope length (scale)	High
HEC-6T	Channel Characteristics	Allows for detailed estimation of channel hydraulic conditions	Simplified based on limited field data and 2-foot topographic mapping	Moderate
	Integration with WEPP Model	Uses triangular unit hydrograph techniques	Distorts actual hydrograph shape and sediment delivery rates	Moderate
	Channel Erosion	Assumed that none occurs due to algorithm for noncohesive bed sediments and to facilitate contaminant tracking	Channel erosion does occur	Moderate
Actinide Concentration Model	Spreadsheet Computations	Estimates average actinide concentrations, sediment yield, and discharge at each model cross-section	Minimal for calculations, but estimate incorporates uncertainty of all preceding steps.	Low

D.1.2.5 Modeling Data Quality Objectives

The data quality objectives (DQOs) for the erosion modeling effort are set forth in the document "Fiscal Year 2000 Actinide Migration Evaluation Data Quality Objectives, Revision 2." The scope of the modeling DQO document (April 2000) is limited to establishing DQOs for actinide migration modeling and research for the main pathways: runoff/diffuse overland flow, surface water flow, groundwater transport (saturated and unsaturated), erosion transport, and airborne transport. (Note: The goals of the April 2000 modeling DQO document are different from those set forth in "Actinide Migration Study Data Quality Objectives [Revision 3, March 1998], described in Appendix D, Section D.1.1.2.3. The goals of the March 1998 document were to support input data collection.)

The April 2000 modeling document focuses the DQO effort on the overriding goal of the Rocky Flats Cleanup Agreement (RFCA) and the AME goal to protect surface water. The data collected under the conditions of the DQO document will be used to measure and model actinide transport processes, understand and predict actinide concentrations and total loads to surface water, and predict air concentrations and particle deposition via air transport. The modeling and prediction effort will be used to answer questions relating to three time frames, including 1) immediate, 2) near-term, and 3) long-term.

D.1.3 Input Uncertainty

D.1.3.1 Types of Input Uncertainty

Input uncertainty relates to the variability inherent in natural phenomena and the ability to collect data that accurately represent the true characteristics of the associated parameters. Two major types of uncertainty exist with regard to data input errors. The first is *measurement error*, such as data derived from the measurement of rainfall for an event, flow volume and entrained sediment in channels, sediment yield from a hillslope, soil texture, average vegetation characteristics, channel sediment depths, as well as sampling, subsampling, and analytical errors for *in situ* actinide concentrations.

The second category is the *spatial and temporal variability* associated with these data. Parameters such as vegetative cover, soil actinide concentrations, average canopy height and cover, soil texture and particle sizes, rill and interrill covers, average rainfall, and other parameters are subject to spatial and/or temporal variation. Whereas these parameters are known to vary, they are typically represented by a parametric average in the modeling process. Use of an average value represents a loss of information that introduces a degree of uncertainty to the model output. The impacts of averaging may vary from negligible to significant.

Spatial averaging effects are analogous to flying in an aircraft in a mountainous region. For example, assume the average surface elevation for the state of Colorado is 2,112 meters (m) (6,930 feet (ft)), and an aircraft attempts to cruise over Colorado at a constant altitude of 305 m (1,000 ft) above the 2,112 m level. This approach smoothes the actual elevation data for the state and does not convey information on the extreme variation in surface elevation; i.e., indicating nothing about the presence of the Rocky Mountains, and results in an obvious problem. Temporal averaging can also bias modeled estimates. For example, if rainfall meets average expectations during the growing season, but is distributed so that most of it occurs very late in the season, growth and biomass and other parameters may be overestimated. This would, thereby, bias runoff and erosion.

Input uncertainties exist for many of the data parameters that are input to each of the primary models. Table D-3 summarizes key data input uncertainties for the geostatistical and GIS models. In Table D-3, soil samples are listed to have an estimated range of error between 10 and 1,000 percent. Larger relative sampling errors are most likely to be associated with areas containing low actinide concentrations. For instance, if a sample location with a true concentration of 0.1 picoCuries per gram (pCi/g) is analyzed and determined to have a concentration of 1.0 pCi/g, a 1,000 percent error is introduced. This is a large relative error, but the error is quite small in absolute terms, i.e., 0.9 pCi/g. Similarly, if a sample location with a true concentration of 10,000 pCi/g is analyzed and reported to have a concentration of 11,000 pCi/g, the relative error is only 10 percent. In this case, the absolute error is much larger than in the previous example, i.e., 1,000 pCi/g. For decision-making purposes, sampling and estimation errors are most critical around the action level for the PCOC. Final action levels for actinides in surface soils at the RFETS have not been determined.

Table D-4 lists the uncertainties for the erosion and sediment transport models. Uncertainties in the input variables for these models are due to both measurement error and spatial and temporal variability not expressed in the input values as a result of averaging.

Table D- 3. Input Uncertainties: Geostatistical and GIS Models

PRIMARY MODEL	MODEL PARAMETERS	UNITS	DATA USE	DESCRIPTION OF UNCERTAINTY	IMPACT ON MODEL
Geostatistical	Soil samples of actinide concentrations	pCi/g	Spatial estimation and mapping	Sampling error	Significant uncertainty on local actinide concentrations (±10% to ± >1,000%)
	Soil samples of actinide concentrations	pCi/g	Spatial estimation and mapping	Laboratory/analytical error	Uncertainty on local actinide concentrations (±10% to 30%)
	Soil sample locations	State plane coordinates	Spatial estimation and mapping	Survey and/or database input error	Minimal impact to local actinide concentrations (± <1%)
	Number of samples on hillslope	Count	Actinide estimation in block areas	Estimation uncertainty	Variable (5% to over 100%)
GIS	Hillslope contours	Feet above mean sea level	Hillslope modeling	Topographic variations between contours	Smoothing effect may increase erosional output
	Hillslope slope transects	meter/meter	Creates linear model of slope (overland flow path).	Loss of spatial variability and complexity. Relies on professional judgment	Smoothing effect, impact to erosion/deposition results (±10% to 15%)
	Hillslope boundaries	meter and square meters	Defines hillslope areas and lengths.	Relies on professional judgment.	Size and geometry can have large impact on results that are output in units per unit area

Note: In general, larger relative errors are associated with samples that have low actinide concentrations, and low relative errors are associated with samples that have higher actinide concentrations.

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Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Surface Water Discharge Measurements	cubic feet/second	Used to calibrate estimated erosion model runoff to observed stream-flow.	Site discharge is measured with flumes and weirs. Good quantitative data available.	Data collected at 15-minute increments with about ± 5 to 10% error. Collected data only for typical (e.g. 1 to 2-year return period) stormwater runoff events. Gaging equipment damaged in 15-year flood on May 17, 1995, resulting in estimated data for most important event over available period of record.
Total Suspended Solids Concentrations	milligrams/liter	Used to calibrate estimated erosion model sediment yield to observed suspended sediment in stream-flow.	Data from auto-samplers at surface water flumes, analysis of duplicate samples. Good quantitative data available.	Loading Analysis Report determined about 22% relative sample analysis error. Less than 10 samples per station are available. Sampled over approximate 9-year period of record with only one large (i.e., 15-year) event for which there a few data due to damaged equipment during flood.
Soil Composition	percent mass of clay, silt, sand, organic matter	Used in erosion model soil file.	Data were obtained from Site samples/observations and Soil Conservation Service (SCS) Soil Survey. Good quantitative data available.	Sampling and analytical error low, ± 10%; data averaged for roads and hillslope position (top, middle, bottom of slopes) site-wide. Actual site variability not maintained, ±50% error, due to spatial variability. Effect on runoff and erosion estimates may be significant for areas with high variability (see Sensitivity Analysis, Appendix A).
Soil Horizon Thickness	millimeters	Used in erosion model soil file.	Data were obtained from Site observations and SCS Soil Survey. Good quantitative data available.	Averaged for entire Site for three soil types. Actual variability not maintained. Effect on sediment yield and runoff estimates slight.
Cation Exchange Capacity	milliequivalents/ 100 grams	Used in erosion model soil file.	Data were obtained from Site sample data and SCS Soil Survey. Good estimates available.	Averaged for entire Site for three soil types. Actual variability not incorporated; effect on sediment yield and runoff estimates slight.
Rock Fragments	percent volume	Used in erosion model soil file.	Data were obtained from Site samples/observations and SCS Soil Survey. Good qualitative descriptions available.	Averaged for entire Site for three soil types. Actual variability not incorporated; effect on sediment yield and runoff estimates slight.

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

MODEL PARAMETERS	UNITS	DATA USE	DESCRIPTION OF DATA SOURCES	DESCRIPTION OF UNCERTAINTY
WEPP-Measured Parameters				
Initial Random Roughness for Rangeland	meters	Used in erosion model soil file; controls time to initiation of runoff.	Data from 1999 Environmental Management Science Project (EMSP) rainfall simulation study and site estimates.	Measurement error; average or estimated values used for entire Site. Actual variability not incorporated.
WEPP-Measured Climate Data				
Precipitation	millimeters	Create climate for erosion modeling of 1995-1998 site conditions	Complete and consistent data from Site meteorological tower, Site Surface Water Group, and the Colorado Department of Public Health and the Environment (CDPHE) for 1995-1998	Precipitation actually varies across the Site, especially for convective storms. However, rainfall is uniformly applied in the model. Slight effect on long-term simulations. Possible moderate effect on single storm simulations.
Rainfall Intensity	millimeters/hour	Create climate for erosion modeling of 1995-1998 site conditions	Complete and consistent data from Site meteorological tower, Site Surface Water Group, and CDPHE for 1995-1998	Intensities vary across Site for specific event. Only one storm per day is applied in the model. Rainfall occurring off and on during the day is compiled into one, continuous storm with single peak intensity. Effects as above.
Storm Duration	hours	Create climate for erosion modeling of 1995-1998 site conditions	Complete and consistent data from Site meteorological tower, Site Surface Water Group, and CDPHE for 1995-1998	Same as above.
Air Temperature	degrees Celsius	Create climate for erosion modeling of 1995-1998 site conditions	Complete and consistent data from Site meteorological tower, Site Surface Water Group, and CDPHE for 1995-1998	Very low uncertainty. Data collected on 15-minute and/or hourly intervals. If minimum temperature below 0 degrees Celsius (°C), WEPP applies precipitation as snow. Data for 1995-1998 was edited so form of precipitation agreed with record. Slight effect for long-term simulation.
Wind Speed and Direction	meters/second and degrees from North	Create climate for erosion modeling of 1995-1998 site conditions	Complete and consistent data from Site meteorological tower, Site Surface Water Group, and CDPHE for 1995-1998	Very low uncertainty. Data collected on 15-minute and/or hourly intervals. No effect on erosion or runoff estimates.

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
WEPP-Estimated Climate Data				
Precipitation, Intensity, Duration, Temperature, Wind Speed, etc.	various	WEPP climate module (CLIGEN) creates climate for 100-year erosion modeling simulation	ARS Station data for Fort Collins; complete and consistent data for 92-year period of record	Average annual precipitation for CLIGEN 100-year climate files created from the Fort Collins data varies by 10 to 15% annually. Matches well with Site data for period of record. Slight effect on estimated runoff and erosion.
WEPP Hillslope Dimensions				
Width	meters	Erosion Model Structure of Individual Hillslopes	GIS techniques obtained dimensions from 2-foot digital mapping from ortho-corrected photographs.	Likely less than ±5% error. Calculated by dividing average hillslope length into the area. Error carries through to sediment yield estimate, which is expressed per meter of slope width.
Length	meters	Erosion Model Structure of Individual Hillslopes	GIS techniques obtained dimensions from 2-foot digital mapping from ortho-corrected photographs. GIS-estimated slope lengths were maintained.	Likely less than ±5% error. Hillslope length generally preserved in the model due to influence on soil loss.
Slope Aspect	Degrees from North	Erosion Model Structure of Individual Hillslopes	GIS techniques were used to obtain orientation from digital mapping obtained from ortho-corrected photographs.	Variable has no observed affect on model output.
Hillslope Delineation	NA	Erosion Model Structure of Individual Hillslopes	Drainage Master Plan sub-basins used as a guide to delineate hillslopes on topographic mapping.	Manual drainage basin delineation is subject to error of interpreting topographic mapping. Slight to moderate effect on estimates.
WEPP Vegetation Cover and Growth Characteristics				
Maximum standing live biomass	kilograms/square meter	Used in the Erosion Model Plant Growth Model	Measured growth and cover data from Ecological Monitoring Program. Parameters adjusted in model so output matched data.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Moderate model sensitivity, slight to moderate overall effect on runoff and erosion estimates. (Refer to Tables A-1 and A-2.)

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Standing biomass where canopy cover is 100%	kilograms/square meter	Used in the Erosion Model Plant Growth Model	Measured growth and cover data from Ecological Monitoring Program. Parameters adjusted in model so output matched data.	Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. No model sensitivity (Table A-1).
Average canopy diameter for grasses	meters	Used in the Erosion Model Plant Growth Model	Measured growth and cover data from Ecological Monitoring Program. Parameters adjusted in model so output matched data.	Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Slight model sensitivity (Table A-1).
Average height for grasses	meters	Used in the Erosion Model Plant Growth Model	Measured growth and cover data from Ecological Monitoring Program. Parameters adjusted in model so output matched data.	Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Slight model sensitivity (Table A-1).
Average number of grasses along a 100-meter (m) belt transect	NA	Used in the Erosion Model Plant Growth Model	Measured growth and cover data from Ecological Monitoring Program. Parameters adjusted in model so output matched data.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Moderate model sensitivity (Table A-1).
Maximum herbaceous plant height	meters	Used in the Erosion Model Plant Growth Model	Measured growth and cover data from Ecological Monitoring Program. Parameters adjusted in model so output matched data.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Slight model sensitivity (Table A-1).
Minimum amount of live biomass	kilograms/square meter	Used in the Erosion Model Plant Growth Model	Estimated by Ecological Monitoring Program personnel. Parameters adjusted in model so output matched data.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Moderate model sensitivity (Table A-1).
Root biomass in top 10 centimeters (cm)	kilograms/square meter	Used in the Erosion Model Plant Growth Model	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. No model sensitivity (Table A-2).

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	UNITS	DATA USE	DESCRIPTION OF DATA SOURCES	DESCRIPTION OF UNCERTAINTY
Average canopy diameter for shrubs	meters	Used in the Erosion Model Plant Growth Model	Estimated by Ecological Monitoring Program personnel. Parameters adjusted in model so output matched data.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Slight model sensitivity (Table A-1).
Average height of shrubs	meters	Used in the Erosion Model Plant Growth Model	Habitat characterization height data for shrubs from the 1997 Preble's meadow jumping mouse data sets were used (Kaiser-Hill, 1998b). Parameters adjusted in model so output matched data.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Slight model sensitivity (Table A-1).
Average number of shrubs along a 100-m belt transect	NA	Used in the Erosion Model Plant Growth Model	Estimated by Ecological Monitoring Program personnel and adjusted to calibrate plant growth component of WEPP.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Moderate model sensitivity (Table A-1).
Average canopy diameter for trees	meters	Used in the Erosion Model Plant Growth Model	Estimated and adjusted to calibrate plant growth component of WEPP.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Slight model sensitivity (Table A-1).
Average height for trees	meters	Used in the Erosion Model Plant Growth Model	Estimated and adjusted to calibrate plant growth component of WEPP.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Slight model sensitivity (Table A-1).
Average number of trees along a 100-m belt transect	NA	Used in the Erosion Model Plant Growth Model	Estimated and adjusted to calibrate plant growth component of WEPP.	Data averaged by habitat and applied to entire Site. Spatial variability not maintained. Used to calibrate WEPP plant growth output to measured data. Moderate model sensitivity (Table A-1).
Average rainfall during growing season	millimeters	Used in the Erosion Model Plant Growth Model	Complete and consistent data from Site meteorological tower, Site Surface Water Group, and CDPHE for 1995-1998.	Average value with moderate variability. Low uncertainty.

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Minimum temperature to initiate growth	degrees Celsius	Used in the Erosion Model Plant Growth Model	Estimated for various plant communities, based on literature and professional judgement.	Uncertainty $\pm$20%. Moderate model sensitivity (Table A-1).
Frost-free period	days	Used in the Erosion Model Plant Growth Model	Data from Site meteorological tower, Site Surface Water Group, and CDPHE for 1995-1998. Also from Fort Collins data used for weather simulation.	Average value with moderate variability. Low uncertainty.
Day of peak standing crop, first peak	Julian day	Used in the Erosion Model Plant Growth Model	Value estimated by Ecological Monitoring Program personnel. Parameters adjusted in model so output matched data.	Applied by habitat across entire Site. Spatial variability not maintained.
Day on which peak occurs, second growing season	Julian day	Used in the Erosion Model Plant Growth Model	Value estimated by Ecological Monitoring Program personnel. Parameters adjusted in model so output matched data.	Applied by habitat across entire Site. Spatial variability not maintained.
Minimum temperature to initiate senescence	degrees Celsius	Used in the Erosion Model Plant Growth Model	Value estimated by Ecological Monitoring Program personnel. Parameters adjusted in model so output matched data.	Applied by habitat across entire Site. Spatial variability not maintained.
Daily removal of surface residue by insects	kilograms/square meter	Used in the Erosion Model Plant Growth Model	Estimated; model default used.	Slight effect on plant cover parameters and runoff and erosion.
Fraction of first peak of growing season	fraction	Used in the Erosion Model Plant Growth Model	Value estimated by Ecological Monitoring Program personnel. Parameters adjusted in model so output matched data.	Applied by habitat across entire Site. Moderate model sensitivity (Table A-1).

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Fraction of second peak of growing season	fraction	Used in the Erosion Model Plant Growth Model	Value estimated by Ecological Monitoring Program personnel. Parameters adjusted in model so output matched data.	Applied by habitat across entire Site. Moderate model sensitivity (Table A-1).
Initial residue mass above the ground	kilograms/square meter	Calibrates amount of soil cover	Measured growth and cover data from Ecological Monitoring Program and adjusted to calibrate vegetation and cover output.	Parameter value based on calibration of model to measured data. Moderate model sensitivity (Table A-1).
Initial residue mass on the ground	kilograms/square meter	Calibrates amount of soil cover	Estimated from measured growth and cover data from Ecological Monitoring Program and adjusted to calibrate vegetation and cover output	Parameter value based on calibration of model to measured data. High variability, moderate model sensitivity (Table A-1).
Interrill litter surface cover	percent	Calibrates amount of soil cover	Measured cover data from Ecological Monitoring Program and adjusted to calibrate vegetation and cover output	Parameter value based on calibration of model to measured data. High variability, high model sensitivity (Tables A-1 and A-2).
Interrill rock surface cover	percent	Calibrates amount of soil cover	Measured cover data from Ecological Monitoring Program and adjusted to calibrate vegetation and cover output	Parameter value based on calibration of model to measured data. High variability, high model sensitivity (Tables A-1 and A-2).
WEPP Erosion Model Calibration Parameters				
Interrill basal surface cover	percent	Calibrates amount of soil cover	Measured cover data from Ecological Monitoring Program and adjusted to calibrate vegetation and cover output	Parameter value based on calibration of model to measured data. High variability, high model sensitivity (Tables A-1 and A-2).
Interrill cryptogramic surface cover	percent	Calibrates amount of soil cover	No estimates available; value of zero used.	High variability, low impact on model estimates due to calibration of model.

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Rill litter surface cover	percent	Calibrates amount of soil cover	Measured cover data from Ecological Monitoring Program and adjusted to calibrate vegetation and cover output	Parameter value based on calibration of model to measured data. High variability, high model sensitivity (Tables A-1 and A-2).
Rill rock surface cover	percent	Calibrates amount of soil cover	Measured cover data from Ecological Monitoring Program and adjusted to calibrate vegetation and cover output	Parameter value based on calibration of model to measured data. High variability, high model sensitivity (Tables A-1 and A-2).
Rill basal surface cover	percent	Calibrates amount of soil cover	Measured cover data from Ecological Monitoring Program and adjusted to calibrate vegetation and cover output	Parameter value based on calibration of model to measured data. High variability, high model sensitivity (Tables A-1 and A-2).
Rill cryptogamic surface cover	percent	Calibrates amount of soil cover	No estimates available; value of zero used.	High variability, low impact on model estimates due to calibration of model.
Total foliar (canopy) cover	percent	Calibrates amount of soil cover	Measured cover data from Ecological Monitoring Program, adjusted to calibrate vegetation and cover output.	Parameter value based on calibration of model to measured data. Average value used. Estimated variability ±10 to 25%. High model sensitivity (Tables A-1 and A-2).
Change in surface residue mass coefficient	NA	Calibrates amount of soil cover	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Parameter value based on calibration of model to measured data. Varies with plant residue type. Smoothing effect.
Carbon:Nitrogen ratio of residue and roots	ratio	Calibrates residue and root decay	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Parameter value based on calibration of model to measured data. Varies with plant type. Smoothing effect.

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Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Fraction of live and dead roots from maximum at start of year	fraction	Calibrates root growth	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Adjusted during vegetation calibration. Sensitivity analysis showed low model sensitivity (Appendix A).
Coefficient for leaf area index	NA	Calibrates leaf area and cover	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Adjusted during calibration of vegetation growth. Moderate model sensitivity (Table A-1).
Change in root mass coefficient	NA	Calibrates root growth	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Adjusted during calibration of vegetation growth. Moderate model sensitivity (Table A-1).
Parameter value for canopy height equation	NA	Calibrates canopy height	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Adjusted during calibration of vegetation growth. Slight model sensitivity (Table A-1).
Projected plant area coefficient for grasses	NA	Calibrates cover	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Adjusted during calibration of vegetation growth. Slight model sensitivity (Table A-1).
Plant drought tolerance factor	NA	Calibrates plant response to drought	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Can be important for continuous simulation in years of low rainfall. Moderate model sensitivity (Table A-1).

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Projected plant area coefficient for shrubs	NA	Calibrates shrub growth	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Parameter adjusted based on calibration. Slight model sensitivity (Table A-1).
Projected plant area coefficient for trees	NA	Calibrates tree growth	Estimated from WEPP documentation for similar plant communities and adjusted to calibrate plant growth component of WEPP.	Parameter adjusted based on calibration. Slight model sensitivity (Table A-1).
Fraction of initial standing woody biomass	percent	Calibrates tree growth	Initial estimate of 70% used for those communities with trees or high shrub populations; used WEPP documentation and adjusted to calibrate plant growth component of WEPP.	Parameter based on estimates from site data and calibration of model. Moderate model sensitivity (Table A-1) .
Initial snow depth	meters	Useful for winter simulation, single storm mode	An initial snow depth of zero was assumed.	No effect on current modeling. No model sensitivity (Table A-1).
Initial depth of thaw	meters	Useful for winter simulation, single storm mode	Estimated from Site weather data.	No effect on current modeling. No model sensitivity (Table A-1).
Initial frost depth	meters	Useful for winter simulation, single storm mode	Estimated from Site weather data.	No effect on current modeling. No model sensitivity (Table A-1).
Soil Effective Hydraulic Conductivity (Ke)	millimeters/hour	Calibrates hillslope runoff	Initially calibrated to EMSP rain simulator data then adjusted to match overall watershed runoff coefficient for the May 17, 1995, storm.	A derived parameter, values varied by hillslslope. Most hillslopes set to match runoff for May 17,1995, event and adjusted for hillslope length, topography, vegetation ,and soil type.

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Soil Saturation	percent	Calibrates hillslope runoff, single storm mode	For design events adjusted soil saturation for the May 17, 1995, and 35 mm storms to the WEPP-estimated saturation predicted on May 17, 1995, in 100-year continuous simulation. Other storms used average dry period soil saturation from 100-year continuous simulation.	Considerable uncertainty is associated with percent soil saturation. The saturation was only adjusted for design storms in WEPP's single-storm mode. These storms (with the exception of the May 17, 1995 storm) are all design storms and do not represent actual measured events. The saturation need only be consistent for each event. No data are available for the May 17 event for comparison.
Rill Erodibility (Kr)	s/m	Calibrates hillslope erosion due to concentrated flow	Calibrated to EMSP rain simulation study data and Site hillslope lengths (scale).	This derived parameter with high sensitivity to hillslope scale has a profound impact on WEPP-estimated erosion. Influence decreases with slope length. High uncertainty.
Interill Erodibility (Ki)	kg*s/m^4	Calibrates hillslope erosion due to sheet flow	Calibrated to EMSP rain simulation study data and Site hillslope lengths (scale).	This derived parameter with high sensitivity to hillslope scale has a profound impact on WEPP-estimated erosion. Parameter was calibrated to account for approximately 2% of total erosion on 10-m slope length. Influence increases with slope length. High uncertainty.
Soil Critical Shear Stress (tc)	N/m^2	Calibrates percentage of rill erosion and where it occurs downslope	Calibrated to perform well for EMSP rain simulation study data and Site hillslope lengths (scale).	Derived parameter with high sensitivity to hillslope scale has a profound impact on WEPP-estimated erosion. Value used remained constant after calibration. High uncertainty.
HEC-6T Model Measured Parameters				
Hydrograph Data: Discharge at each time step over the duration of the runoff events	cfs	Sediment transport model calibration parameter	Peak runoff from WEPP output used to construct hydrographs for each event for each hillslope inflow, HEC-6T then constructs a hydrograph for the entire watershed.	Triangular unit hydrograph method of converting WEPP output into HEC-6T input tends to distort hydrograph shape. Less than 10% error between WEPP output and HEC-6T output for each hillslope.

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Surface Water Discharge Measurements	cubic feet/second	Used for calibration of model.	Site discharge is measured with flumes and weirs.	Data collected at 15-minute increments with about ±5 to 10% error. Collected data only for typical (e.g. 1- to 2-year return period) stormwater runoff events. Gaging equipment damaged in 15-year flood on May 17, 1995; resulting in estimated data for most important event over available period of record.
Total Suspended Solids Concentrations	milligrams/liter	Used for calibration of model.	Auto-sampled at flumes. Analysis of duplicate samples in the Loading Analysis Report.	Loading Analysis Report determined about 22% relative sample analysis error. Less than 10 samples per station are available. Sampled over approximate 9-year period of record with only one large (i.e., 15-year) event for which there a few data due to damaged equipment during flood.
Channel cross-section dimensions (geometry)	feet	Sediment transport model calibration Parameter	Field measurements, 2-foot contour mapping (GIS). EG&G SID capacity study (1992).	Channel cross-section geometry is smoothed, based on resolution of field measurements. This does not significantly affect the sediment model output.
Bed sediment size gradation	percent finer in millimeters	Sediment transport model calibration parameter for erodible bed material.	Field measurements/observations	No affect on results due to no channel erosion allowed in models. Most Site channels have cohesive (clay) sediments, which are not highly erodible.
Locations of tributary inflows	meters	Sediment transport model calibration parameter	Tributary inflows enter at middle of each hillslope to account for change from diffuse source to point source.	Likely increase sediment transport rates due to concentrated tributary flow entering channel instead of diffuse overland flow.
Sediment concentration vs. discharge relationship for tributary inflows and baseflow	Discharge in cubic feet per second (cfs); Sediment load in tons/day	Sediment transport model calibration parameter	Erosion Model output for tributaries, monitoring data for industrial area flows, Site monitoring data for baseflow. Provides flow and sediment loading for each hillslope.	Triangular unit hydrograph method of converting WEPP output into HEC-6T input tends to distort hydrograph shape. Less than 10% error between WEPP output and HEC-6T output for each hillslope.

Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Manning's n-value for channel roughness	seconds	Sediment transport model calibration parameter that defines resistance to flow in channel.	Estimated calibration parameter (Van Haveran, 1991)	A derived parameter, Manning's n-value has a profound impact on model results. The roughness impacts the water depth and velocity, which in turn, determines how much sediment can be transported. Used to calibrate sedimentation.
Fine bed sediment depth	feet	Sediment transport model calibration parameter	Estimated/calibration parameter. Defines erodible bed in channel. Set to zero in current models.	A derived parameter currently used to turn off bed erosion to study effects of hillslope sediment and actinide inputs and determine channel sinks.
Bed area available for erosion	percent	Sediment transport model calibration parameter	Estimated/calibration parameter. Defines erodible bed in channel. Set to zero in current models.	A derived parameter currently used to turn off bed erosion to study effects of hillslope sediment and actinide inputs and determine channel sinks.
Specific gravity of suspended sediment	grams/cubic cm	Sediment transport model calibration parameter	WEPP model output	Actual specific gravity may differ from WEPP output. WEPP estimated based on field data. Expected error ±10 to 20%.
Plutonium-239/240 and Americium-241 Soil Activities	pCi/g	Used for kriging distributions	Site database; about 2,000 samples were used in a kriging analysis to map spatial distribution of Pu-239/240 and Am-241 in Site soils.	Significant uncertainty on local actinide concentrations (± 10% to ± >1,000%). Kriging uncertainty is quantified above.
Plutonium-239/240 and Americium-241 particle size associations	percent mass	Used for actinide transport modeling	Data from CSM investigation of actinide size distribution and aggregate stability. About 30 samples analyzed.	Uncertainty in three sets of three replicates for each size-fraction averaged 8.3%.
HEC-6T Model Measured Parameters				
Water-stable soil aggregate size distributions	percent mass	Used for actinide transport modeling	Data from CSM investigation of actinide size distribution and aggregate stability.	CSM data show about 30 samples analyzed with good precision. Duplicate samples had average error of 6.3% for <10 micrometers (μm), and 23% for 2 μm sizes. Greater error in smallest fraction due to low percentage of total mass.

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Table D-4. Identified Sources of Uncertainty for Erosion and Sediment Transport Modeling to Determine Actinide Concentrations in Site Streams, continued

WEPP-Measured Parameters				
MODEL PARAMETERS	**UNITS**	**DATA USE**	**DESCRIPTION OF DATA SOURCES**	**DESCRIPTION OF UNCERTAINTY**
Sediment deposition in the SID and ponds	inches	Estimated from cores and used for calibration	RFETS OU RI/FS data. AME cores collected for analysis in 1999. Sediment depths determined by visual and tactile inspection.	Cores obtained from four locations in SID. Five locations cored in each of the A-, B-, and C-series ponds. High uncertainty due to observational nature of estimates.

D.1.3.2 Sample Sufficiency

A form of spatial variability that significantly impacts the geostatistical model is the number and spatial distribution of the sample data for actinide concentrations. Samples are required to estimate the actinide concentrations in soils on each hillslope. However, the approximately 2,200 samples used to estimate actinide concentrations are not evenly distributed. This means that hillslopes will have more or fewer samples used to estimate the actinide concentrations. More samples generally provide a better assessment of the average concentrations, but the uncertainty associated with the estimation is also a function of the variability of the samples on or near a particular hillslope.

Table D-5 contains a summary of the sample apportionment in relation to the hillslopes in the three drainages (Woman Creek, SID, and Walnut Creek). As the table shows, about 40 percent of the hillslopes do not contain any samples. Another 25 percent of the hillslopes are estimated where one sample is used to estimate four hectares. At the other end of the spectrum, three percent of the hillslopes have, on average, more than 25 samples per hectare.

The number of samples can be used to assess the reduction in the uncertainty associated with the average actinide soils concentrations on the hillslopes. Based on the data presented in Table D-5, uncertainty reduction ranges from less than 10 to approximately 95 percent, depending on the number of samples per hectare. The disparity in sampling density indicates selective clustering of sample data across the Site. The clustering is related to the conceptual model of the contaminant distribution at the site. Fewer samples were taken in areas that were not suspected to be impacted severely. Conversely, many samples were concentrated in areas known to have been impacted significantly by contamination, such as the 903 Pad and areas to the east of the 903 Pad.

By structuring sampling density according to the conceptual model, certain efficiencies are gained. Unimpacted areas need not be intensively sampled, where high relative uncertainties translate to relatively low absolute differences between concentrations, especially where concentrations are near background. Conversely, impacted areas need a greater sampling density to understand the extent and variability of the contamination, especially around potential action levels. In higher concentration zones, small relative differences can translate into relatively large absolute differences, often impacting action levels.

Uncertainties associated with the number of samples used on hillslopes are shown above in Table D-3. Whereas some of the uncertainties are quite large, a mitigating factor is that the largest uncertainties tend to be those slopes with the lowest actinide concentrations (<1.0 pCi/g).

Table D-5. Sample Representation by Hillslope

PERCENTAGE OF WEPP MODEL HILLSLOPES	NUMBER OF SAMPLES AVAILABLE PER HECTARE
40	0
25	<0.25
21	0.25 to 2.5
11	2.5 to 25
3	>25

D.1.3.3 Data Quality Objectives for Modeling

The data quality objectives (DQOs) for data collection to support the AME were outlined in "Actinide Migration Study Data Quality Objectives" (Revision 3 March 1998). The DQO process followed the United States Environmental Protection Agency's (USEPA) seven-step framework (USEPA, 1994) and established the necessary quality for the input data to the AME mathematical models. The DQO document established data quality needs for runoff/diffuse overland flow and surface water flow. Table D-6 lists the DQOs achieved for the AME modeling data. (Note: The DQOs for data collection outlined in the March 1998 document are different than those set forth in the April 2000 DQO document, which addressed data for measuring and modeling actinide transport processes.)

D.1.4 Parameter Uncertainty

Computer models of physical systems generally contain internal parameters that are fixed and that may or may not be available for adjustment by the user. For example, the WEPP model calculates the midpoints of particles size distributions through an internal program routine that is not adjustable by the user. Other examples are the climate generation model, where the Log Pearson III approach is used by default, certain contouring algorithms where all internal parameters are fixed, and certain types of geostatistical analyses involve logarithmic transformations. Model parameter uncertainties are summarized in Table D-7.

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Table D- 6. Data Quality Objectives

ACTINIDE MIGRATION PATHWAYS/PROCESSES	POTENTIAL MODEL NEEDS	LIMITS ON DATA UNCERTAINTY
Diffuse Overland Flow/Soil Erosion	Soil Particle Size and Actinide Association	Percent Colloid, Clay, Silt, Sand, Aggregates/Distribution of Actinides with (MDA ≡ 0.3 pCi/g)
	Soil Isotopic Activity	MDA = 0.3 pCi/g See Attached Limits on Data Uncertainty
	Hill Slopes	2-Foot Contour Interval Resolution
	Channel Geometry	2-Foot Contour Interval Resolution
	Catchment Characteristics	2-Foot Contour Interval Resolution
	Climate/Precipitation	Precipitation =0.01 inches Temperature = 1°C Wind = 1 miles per hour (mph)
	Vegetation (canopy, cover, and type)	OU Investigation Data
	Rill/Inter-Rill Characteristics	Visual Observations/Professional Judgement
	Soil Characteristics	Soil Type, Texture, Bulk Density, Conductivity (high variability)
	Soil Particle Size and Actinide Association	Percent Colloid, Clay, Silt, Sand, Aggregates/Distribution of Actinides (high variability)
	Soil Isotopic Activity	MDA = 0.3 pCi/g See Attached Limits on Data Uncertainty
	Mineral Composition of Surface Soils	Percent Mineral Composition (high variability)
	Soil Organic Content/Characteristics	Percent Organic Content/Type (high variability)
	Surface Water Data for Validation and Verification (See Surface Water Flow)	Discharge: ±5%, TSS: 1 mg/L Activity: 0.03 pCi/L Grain Size Distribution to 2 □m.
	Suspended Solids Grain Size Distribution	Distribution should include size range from 200 □m to 2 □m.
Surface Water Flow/Sediment and Particulate Transport	Surface Water Isotopic Activity	MDA = 0.3 pCi/g. See Attached Limits on Data Uncertainty
	Stream Discharge	0.1 cubic feet per second
	Surface Water and Sediment Isotopic Activity	MDA = 0.3 pCi/g See Attached Limits on Data Uncertainty
	Distribution of Actinides Over Range of Particle Sizes	Distribution should include size range from 2 to 200 □m
	TOC	MDL = 0.1 mg/L
Surface Water Flow/Sediment and Particulate Transport (continued)	Sediment Sources/Sinks	2-Foot Contour Mapping, Visual Observations, Vegetation Mapping
	Total Suspended Solids/Sediment Concentration	Detection Limit = 1 mg/L

Table D-6. Data Quality Objectives, continued

ACTINIDE MIGRATION PATHWAYS/PROCESSES	POTENTIAL MODEL NEEDS	LIMITS ON DATA UNCERTAINTY
Surface Water Flow/ Dissolution and Solute Transport	See Data Needs for Diffuse Overland Flow/Dissolution and Transport of Solution Species Process	See Data Needs for Diffuse Overland Flow / Dissolution and Transport of Solution Species Process
	pH	0.1 pH Units
	Eh	0.1 Eh Units
	Temperature	1 °C
	TOC	0.1 mg/L
	DOC	0.1 mg/L
	Residence Time/Travel Time	±5%
Surface Water Flow/ Dissolution and Solute Transport	Sediment Geochemistry: Actinide Oxidation State and Phase Association (Kd)	To Be Determined. See Attached Limits on Data Uncertainty
	Gaining/Losing Stream Segments	100-foot Resolution on Stream Reaches. Flow = ±5%
	Channel Environments (e.g., wetlands, deep water, riparian, etc.)	2-Foot Contour Interval Mapping GIS Mapping

[MDA = Minimum Detectable Activity; MDL= Minimum Detection Limit; pCi/g = picocuries/gram; mg/L=milligrams/liter; OU=Operable Unit; µm = microns]

Table D- 7. Parameter Uncertainties

PRIMARY MODEL	UNCERTAINTY/ LIMITATION	IMPACT ON MODEL	MAGNITUDE OF IMPACT
Geostatistics	Choice of distance weighting functions	Estimation uncertainty	Negligible
GIS	Choice of projection and map units	May require unit conversion	None
WEPP	Hillslope length (watershed scale) affects runoff and erosion estimation.	Runoff and erosion will decrease with increasing hillslope length beyond about 100 m.	Introduction of error into estimates can be considerable if unaware of relationship. The effect can be controlled through adjustments in a combination of several parameters.
HEC-6T	Yang's sediment transport equation uses channel roughness for hydraulic calculations but not for roughness applied to suspended particles. Adjustment of Manning's n-values simulates channel roughness that will act directly on the particles.	Calibration to simulate in-stream roughness from vegetation (e.g. cattails, rushes, etc.). Does not seem to allow fine materials to settle out in deposition areas.	Sediment and actinide transport are generally overestimated.

D.2 Generated or Derived Uncertainties

Use of input data and program parameters by the models creates additional uncertainties, which are then associated with the model output. For example, the geostatistical process of kriging generates an estimation uncertainty for each block area that it estimates. This estimation error occurs even if the sample data concentrations are known exactly and is derived from the fact that estimating unsampled areas is subject to uncertainty.

In the GIS model, not all of the kriged actinide block concentrations are used as they exist in the kriged model, which introduces uncertainties and biases. Due to occasional large spacings between transect lines that define slope for input into WEPP, certain kriged blocks and their associated actinide concentrations are not used in the erosion model. This exclusion of blocks creates an uncertainty in the concentration of actinides in the eroded sediment. Sensitivity tests have determined that blocks that are skipped in the erosion model are almost exclusively located in areas where the Pu-239/240 and Am-241 concentrations are below 1 pCi/g. The impact on the model is also very low, because the concentrations of the skipped blocks are quite low.

The exclusion of block concentrations in the model is related to another issue of scale. There is frequently a tendency to create kriged grids using relatively small blocks. Generally, the hope is to increase the resolution of the map. In fact, the obtainable resolution is a function of sample density, not block size. Smaller blocks can provide greater resolution only if there are sufficient sample data to support such finer concentration delineation.

At the RFETS, the 903 Pad area and areas to the east and south have a relatively high sampling density. The site-wide 75-ft by 75-ft grid could probably be reduced in this area of higher sampling density to reduce the smoothing effects of kriging and gain higher resolution. However, at some point, the reduction in block size will not be effective for two reasons. The first is due to the sample density issue previously discussed, and the second is that the GIS model will begin to miss blocks.

This potential increase in resolution should be weighed against the effects on the model in other parts of the site. In most other areas, sampling density is much less than around the 903 Pad. As described above, the GIS model skips some blocks in sparsely sampled areas. Therefore, the tradeoff becomes one of increased resolution in the 903 Pad areas vs. increased uncertainty in other parts of the Site.

The $522.6m^2$ (75-ft by 75-ft) blocks are able to capture a significant range of concentrations (as shown in the kriged maps in Appendix B), and no blocks are being missed in the erosion model, thereby providing reasonable data to the model. In contrast, these same-sized blocks are being skipped in other portions of the model, although, as discussed above, with relatively little impact. The $522.6m^2$ grid appears to do an adequate job of modeling the actinide contamination, considering that the same size block needs to be used Site-wide in the GIS model.

Table D-8 summarizes the generated and derived uncertainties arising from the primary models.

D.3 Assumptions Relating to Uncertainty

Numerous assumptions have been made during the modeling processes as well as in the integration of the primary models. These assumptions contribute to the uncertainty of the overall model. Table D-9 lists the assumptions used in the various modeling processes.

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D.4. Sources of Conservatism

D.4.1 Benefits to the Model

Various decisions relating to data inputs or modeling parameters are subject to professional judgment, available resources (time and budget), and other factors. These situations offer opportunities to incorporate appropriate levels of conservatism into the models.

For decision-making in the AME, the general rule was to exercise judgment that would be expected to produce conservative results from the model, i.e., would tend to raise the volumes of erosion, sediment, and radionuclide activity in surface waters, while achieving reasonable calibration to Site data. This approach was considered to be more protective of human health and the environment. Table D-10 lists specific decisions that were made that have contributed to an added level of conservatism in the model.

Table D- 8. Generated or Derived Uncertainties

PRIMARY MODEL	GENERATED UNCERTAINTY	IMPACT ON MODEL	MAGNITUDE OF IMPACT
Geostatistics	Block estimation uncertainty	Errors in actinide concentrations are transmitted to GIS and erosion model.	<u>Entire Site Area</u> Pu: CVs range from 28% to 7,900% Am: CVs range from 84% to 24,800% <u>Plume Area</u> Pu: CVs range from 180% to 2,900% Am: CVs range from 900% to 17,400 % CV = Coefficient of Variation
GIS	Incomplete use of kriged model block values due to hillslope transect spacing	Bias introduced into concentrations attributed to eroded particles.	<u>Geographic Extents</u> - 903 Pad: Transects use all block values. Impact negligible - SID: Missed blocks <10%; all in areas with Pu-239/240 concentrations <1 pCi/g. Impact negligible - Woman Creek: Missed blocks <35%; all in areas with Pu-239/240 concentrations <1 pCi/g. Impact low. - Walnut Creek: Missed blocks <50%; most in areas with Pu-239/240 concentrations <1 pCi/g.

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Table D-8. Generated or Derived Uncertainties, continued

PRIMARY MODEL	GENERATED UNCERTAINTY	IMPACT ON MODEL	MAGNITUDE OF IMPACT
WEPP	Runoff and sediment yield	Significant changes occur at approximately 100 meters downslope depending on rainfall event & vegetation.	Accounted for in calibration phase. Minimal impact on output.
	Vegetation growth/cover	Affects sediment yields up to 50%.	Greatest effect is smoothing due to application of average values for each plant community. Minimal impact if properly calibrated. Cover is calibrated to within 1 standard deviation from the average for Site data from each community using the 100-year annual average for 100-year continuous simulation. The 100-year averages match measured data.
HEC-6T	Manning's n-values	Causes particle deposition/transport	About 20% variability among reasonable n-values selected for channels.
	Triangular unit hydrograph methodology	Distorts runoff hydrograph shape/distribution.	Slightly underestimates peak discharge and overestimates storm duration.
	Hillslopes are modeled as tributary streams to main channels.	Feeds all sediment and flow into channel at discrete confluences as opposed to actual diffuse overland flow along entire channel length.	Likely increases transport of fine sand and coarse silt particles. This is conservative in terms of actinide concentration estimation.
	Stream baseflow is set to a single value and does not increase during storms.	Dilution of sediment concentration with baseflow does not occur.	Because storms are of short duration, there is little to no affect from continuous baseflow.

Table D- 9. Assumptions Relating to Uncertainty

PRIMARY MODEL	ASSUMPTION	IMPACT ON THE MODEL	MAGNITUDE OF IMPACT
Geostatistical	Multiple statistical domains for actinide concentration in soils	Division of kriged model into separate domains for estimation	High degree of accuracy achieved in areas where actinide concentrations exhibit large differences (approximately 2 orders of magnitude or more) over relatively short distances
	Stationarity	Simplification of spatial statistical model	Minimal to low due to domain partitioning and restriction on number of samples used for block estimation
	Samples of any support can be used for spatial continuity analysis and spatial estimation	Increase/decrease in localized variability for smaller/larger support sizes, respectively	Accuracy increased as a result of increased sample information

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Table D-9. Assumptions Relating to Uncertainty

PRIMARY MODEL	ASSUMPTION	IMPACT ON THE MODEL	MAGNITUDE OF IMPACT
WEPP	Vegetation cover and growth characteristics remain constant site-wide	No accounting for spatial variability	Low to moderate
	Soil characteristics are averaged Site-wide by location on hillslopes: top, middle, and bottom of slopes and for roads/disturbed areas.	Simplification does not account for all spatial variability.	Low
	Synthetic climate generated from 92-year Fort Collins, Colorado, record (representative of Site conditions).	Only four years of actual Site data were suitable for incorporation into climate file. Fort Collins storms appear to be somewhat more intense than at Site, but they are of similar rainfall amounts.	Low and conservative
	Hillslope delineation and average slope from transects drawn on hillslopes in GIS are representative of hillslope topography.	Simplification of model for Site watersheds does not incorporate all topographic features that may affect sediment yields (e.g., roadside ditches, swales, etc.)	Creates smoothing effect. Moderate effect on results is expected. More hillslopes and more detailed slope data would make the model more logistically complex with potentially little to no increase in accuracy.
GIS	Particles undergo complete mixing as they are transported down and/or deposited on the hillslope.	Simplification of actinide concentration distribution being eroded and deposited	Greater impact in areas where concentrations being mixed are more variable, especially for drainages with multiple hillslopes
	Particle size distributions remain constant site-wide and exhibit no spatial variability.	Spatial variability of the particle sizes not reflected in the model. Also, particle size distributions are based on limited data	Not known, but potentially significant as the particle size distribution is used repetitively in the model
HEC-6T	Streambeds are assumed not to be erodible. HEC-6T models moveable bed as loose sand sitting on the channel bottom.	In reality, stream bed and bank erosion does occur and contributes to sediment yield. However, Site streams are either well armored or have cohesive clay material often with thick vegetation.	Significant impact on model results. Underestimates sediment yields by about 10%.. This approach allows for track sediment and actinide concentrations without dilution by channel erosion. Enables determination of sources and sinks.
	All ponds are modeled as being full with bulk of flow routed over emergency spillways of dams. Simulate flow-through configuration.	During dry periods, ponds would not be full and could contain most to all of storm runoff depending on event size, which would further limit actinide transport.	Significant impact on estimated sediment and actinide concentrations result. This condition decreases sediment residence time in the ponds, which increases sediment and actinide concentrations.
	Baseflow is at a constant value for all models.	Less dilution is predicted than might actually occur.	Probably insignificant, because short duration storms do not have significantly changing baseflow conditions.
	Upstream areas of Woman and Walnut Creeks are not included.	Will produce underestimation of flow for large events.	Conservative effect on actinide concentrations due to no dilution from off-Site sources.
	Industrial Area sediment and actinide concentration is constant for all storms. Average values for Site monitoring data used, because WEPP does not model industrialized areas.	Actual yields and concentrations might be diluted more with increasing flow for larger storms.	Potentially significant impact on results. Likely overestimates actinide transport as dilution with higher flows is expected.

Table D- 10. Sources of Conservatism

PRIMARY MODEL	ISSUE	DECISION DESCRIPTION	BENEFICIAL IMPACT ON MODEL
Geostatistics	Duplicate data values.	Sample with highest actinide concentration was selected.	Marginally higher (<1%) block estimates are more protective of human health and the environment.
	Number of neighbors used in estimation.	Greatest number of samples selected (6) that was consistent with sample location geometries.	Higher (<10% to 30%) block estimates that are more protective of human health and the environment.
GIS	Particles undergo complete mixing as they are transported down and/or deposited on the hillslope.	Simplification of actinide concentration distribution being eroded and deposited.	Smoothing effect on actinide transport estimates. Greater impact in areas where concentrations being mixed are more variable, especially for drainages with multiple hillslopes.
WEPP	Level of topographic detail does not incorporate all sinks for deposition.	Simplification of topography required to run models efficiently and cost effectively.	Runoff and erosion estimates might be too low or too high, which affects surface water actinide concentration estimates.
	Hydraulic conductivity values for soils are based on runoff coefficient for storm event on May 17, 1995, which occurred when soils were very wet.	Calibrated to rain simulator results for runoff. Due to long slope lengths, adjustments were necessary to successfully extrapolate to larger hillslopes. Monitoring data for May 17, 1995, event was used to estimate runoff coefficients. Runoff volumes were compared to gaging station data and adjusted as needed.	Runoff and erosion estimates were calibrated to gaging station data, with a bias not to underestimate flow or sediment yields. This tends to increase sediment and actinide concentrations. Over-estimation is considered to vary from 0 to 5 times the actual. However, other data indicate underestimation by as much as a factor of 2 or more is possible.
	Rill erodibility values are calibrated to produce rill erosion on large hillslopes.	Due to the high density of plant stems, flow is directed to concentrated flow paths. The calibration of this parameter to the simulator data and the long site hillslope, was difficult due to the parameters high sensitivity to slope length.	Erosion estimates are likely conservative on the long hillslopes, increasing surface water sediment and actinide concentrations. Over-estimation is considered to vary from 0 to 5 times actual. However, other data indicate underestimation by as much as a factor of 2 or more is possible.
HEC-6T	Detention ponds modeled as full creating flow-through system.	Only way to make HEC-6T models run (i.e., not crash) and estimate transport for entire watershed(s).	Transport of sediment and actinides is overestimated, especially for intense summer storms when ponds might be nearly empty.
	Hillslopes loaded into channel as tributary streams, not diffuse overland flow.	Only way to route sediment into main channel in the HEC-6T model.	Likely overestimates sediment and actinide transport, because flow is routed into channels in more intense fashion than would actually occur.
	No change (increase) in baseflow.	For short duration storms, changes in baseflow would be negligible.	Reduces actual dilution that could occur. This is especially true for longer storms where off-Site inflows could increase baseflow.

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D.4.2 Caveats Relating to the Conservative Approach

In a good faith effort to eliminate unjustified optimism in a model result, it is not uncommon for modelers to overcompensate with regards to conservatism. However, the result of overcompensation is a model that will not reflect reality for most situations. For example, it is possible to use items such as parameter maximum values, data extremes, 95% upper distribution or confidence limits, and overly conservative assumptions as the basis for modeling input. The outcome of such approaches is often a model that is an unrealistic result, beyond even a "worst case" scenario.

Tables D-11 and D-12 demonstrate how overcompensation can affect the reliability of the model. For a series of independent variables (2, 3, 4, 5, or 6), the tables list the probabilities (Table D-11) and chances of occurrence (Table D-12) for specified levels of confidence and numbers of variables. For example, if parameters are used for which one can expect only a 10% chance of occurrence (90% confidence) for each of three independent variables, the chance that this outcome will actually occur is only 1 in 1,000. At a 1% chance for each of the three variables, the chance is only one in a million. For more than three independent variables at a 99% level of confidence, the chance that the outcome will occur becomes almost impossible (1 in a trillion), especially with regard to a 100-year time frame.

Table D-11. Sensitivities to Conservatism: Parameters and Assumptions

ALPHA ERROR (%)	NUMBER OF INDEPENDENT VARIABLES: PROBABILITY OF OCCURRENCE				
	2	3	4	5	6
0.50	0.2500	0.125000	0.06250000	0.0312500000	0.015625000000
0.40	0.1600	0.064000	0.02560000	0.0102400000	0.004096000000
0.30	0.0900	0.027000	0.00810000	0.0024300000	0.000729000000
0.20	0.0400	0.008000	0.00016000	0.0003200000	0.000064000000
0.15	0.0225	0.003375	0.00050625	0.0000759375	0.000011390625
0.10	0.0100	0.001000	0.00010000	0.0000100000	0.000000100000
0.05	0.0025	0.000125	0.00000625	0.0000003125	0.000000015625
0.01	0.0001	0.000001	0.00000001	000000000001	0.000000000001

Table D- 12. Sensitivities to Conservatism: Parameters and Assumptions

ALPHA ERROR (%)	NUMBER OF INDEPENDENT VARIABLES: ONE IN *x* CHANCE THAT THE EVENT WILL OCCUR				
	2	3	4	5	6
0.50	4	8	16	32	64
0.40	6	16	39	98	244
0.30	11	37	123	412	1,372
0.20	25	125	625	3,125	15,625
0.15	44	296	1,975	13,169	87,791
0.10	100	1,000	10,000	100,000	1,000,000
0.05	400	8,000	160,000	3,200,000	64,000,000
0.01	10,000	1,000,000	100,000,000	10,000,000,000	1,000,000,000,000

Although the AME modeling has eschewed the use of extreme values or values corresponding to high levels of statistical confidence, numerous small decisions or adjustments were made with regard to parameter conservatism. Even at relatively low levels of conservatism, fairly significant impacts on the model can occur. For example, if 25 parameters are each subject to a level of conservatism of 10 percent, there is only about a 1 in 14 chance that this result will occur. By using judicious application of conservatism, professional judgment, and careful calibration, it is estimated that the impacts of conservative parameter input for the AME vary by location with a range from underestimation to over-estimation by a factor of five, not orders of magnitude.

D.5 Compounding of Uncertainty

As described in the previous section, the interaction of several independent variables can result in a significant, even unrealistic effect on the model. Well-intentioned, but inappropriate or excessive, application of conservative parameters can easily cause a model to spin out of control. This is not usually the case, however, as professional judgement and average data are used to produce a result that is, hopefully, more representative of the actual conditions that will result. By stacking the deck to produce a "worst case" scenario, a positive bias is introduced.

In a model created using best judgment, random variations in parameters (sampling and analytical errors, hillslope definition and modeling, etc.) often tend to cancel out the effects if the variations are of the same magnitude. If the variations are not of the same magnitude, a bias will be introduced. In some cases, it may be possible to determine or estimate the magnitude of the bias, but not the sign and, thus, the precise impact on the model. In some cases, nonlinearity of variables may serve to offset the effect of unequal magnitudes, whereas, in others, it may serve to further compound the problem.

In other situations, variables or parameters may be correlated. In this case, errors in one parameter may be propagated and/or amplified by other variables in the system. For example, Chavez and Nearing (1991) found a positive correlation between peak runoff rates and the resulting average soil loss and sediment yield. One can expect this positive correlation to be consistently propagated on all hillslopes. However, depending on the specific nature of the individual slope gradients and erodibility parameters combined with the spatial configuration of the actinide contamination in the soils, an overestimation of peak runoff could serve either to enrich or to dilute actinide concentrations in the runoff waters. Thus, the compounding effect of correlated variables may serve to mitigate the effects of the overestimation or to amplify the problem with a consistently high bias.

The process of model calibration plays a crucial role in the compounding of uncertainty, because it provides a system of checks and balances on the variability and impact of the input parameters. Even though most of the data for the calibration are subject to uncertainty, the model must perform to provide results that can be confirmed by measured data in which a good deal of reliability exists (measured rainfall at the Site, Site surface water flow data, Site-suspended sediment data, etc.).

Still, calibration is subject to non-uniqueness. Many combinations of reasonable (or unreasonable) parameters may yield the same result. Were it not for good judgment, combinations of extreme yet negating parameters might yield a "good" calibration. For this reason, sensitivity analysis is also performed on the model to provide insights for the calibration process. Here, a number of parameters are varied so that a perspective is obtained on the calibration. Sensitivity analysis for the AME is discussed in Appendix A (Tables A-2 and A-3).

Many of the uncertainties have been accounted for, based on the sensitivity analysis and model calibration. In addition, much of the compounding of conservatism has been taken into account and adjusted appropriately. By analyzing the results to date, it is estimated that the model predictions of sediment and actinide concentrations in surface water vary from slight underestimation to over-estimation by a factor of 5.

The model is highly useful as a prioritization and planning tool. The model produces estimates that predict: 1) problem areas that have the greatest impact on site surface water concentrations for actinides; 2) reaches of the drainages where concentrations of Pu and Am will exceed the surface water standards/ action levels for events of specific return periods; 3) potential sinks for sediment associated with Pu-239/240 and Am-241; 4) estimates of the probability of occurrence based on event return periods; and 5) estimates of remediation levels necessary to protect surface water. Other uses for the model are discussed in Section 1 of the report. The model is a valuable planning tool that allows the strategic targeting of areas for cost-effective management or remediation, source control, or strategic monitoring and sampling.

D.6 Concentrations of Actinides in Surface Water

The uncertainties described in this section related to various parts of the erosion transport and sediment model and the associated actinide concentrations. Ultimately, however, these eroded soil concentrations are used to assess the actinide concentrations in surface water. Surface water concentrations are derived directly from the volume of sediment, actinide concentrations in the sediment, and volume of water in the channel. As such, the uncertainties on surface water concentrations for actinides are subject to the same uncertainties as the kriging, GIS, WEPP, and HEC-6T models.

D.7 Conclusions

Due to the complex nature of the individual primary models and submodels along with the complex interaction between the models, it is not possible to derive a single measure of the uncertainty on the overall model predictions, and thus, the impact on surface water. Model inputs as well as their outputs are random variables. Without a stochastic analysis, the range of expected model output values cannot be calculated precisely.

In lieu of a single number or confidence interval, this section has analyzed the uncertainties associated with the models and important input parameters to the models. Despite the numerous uncertainties related to the structural, input, and parameter components, the sensitivity analysis combined with calibration have produced highly useful results. The germane findings of this analysis are as follows:

- Each of the primary models has been selected based on its applicability and robustness in comparison to other available models in the industry;
- Where best professional judgment has been applied, the inputs and results have been peer-reviewed or checked by the project team;
- Sensitivity analysis and model calibrations have identified potential problem areas that were adjusted or checked for adverse impacts;
- The WEPP model was updated and improved to accommodate certain site-specific needs of the Site, making the model more reliable;

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- Literature review has found independent analysis of WEPP uncertainty, which indicates that WEPP is a validated and reliable model for erosion modeling;
- The results of the AME represent the best available prediction model for actinide migration to surface waters, based on current engineering practice and modeling;
- Calibration of the model has successfully removed many of the uncertainties in the model by conditioning results to measured data. Based on the calibration, it is thought that current model predictions of sediment and actinide concentrations range from slight underestimation to over-estimation by a factor of five. However, the data available for comparison to determine this factor are limited, thereby introducing additional uncertainty; and
- Source areas can be distinguished from areas of relatively minor actinide contribution. The worst areas may be selectively prioritized for cost-effective remediation or management at the Site.

D.8 References

All references are located in Section 12 of the main report.

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(The disk is available through the US DOE Office of Communications, (303) 966-_4580_______)

Report on Soil Erosion/Surface Water Sediment Transport Modeling for the Actinide Migration Evaluation at RFETS
August, 2000

Electronic Copy of Analytical Database

Appendix E
No. 00-RF-01823

U.S. DEPARTMENT OF ENERGY

AR Document Number: SW-A-004103

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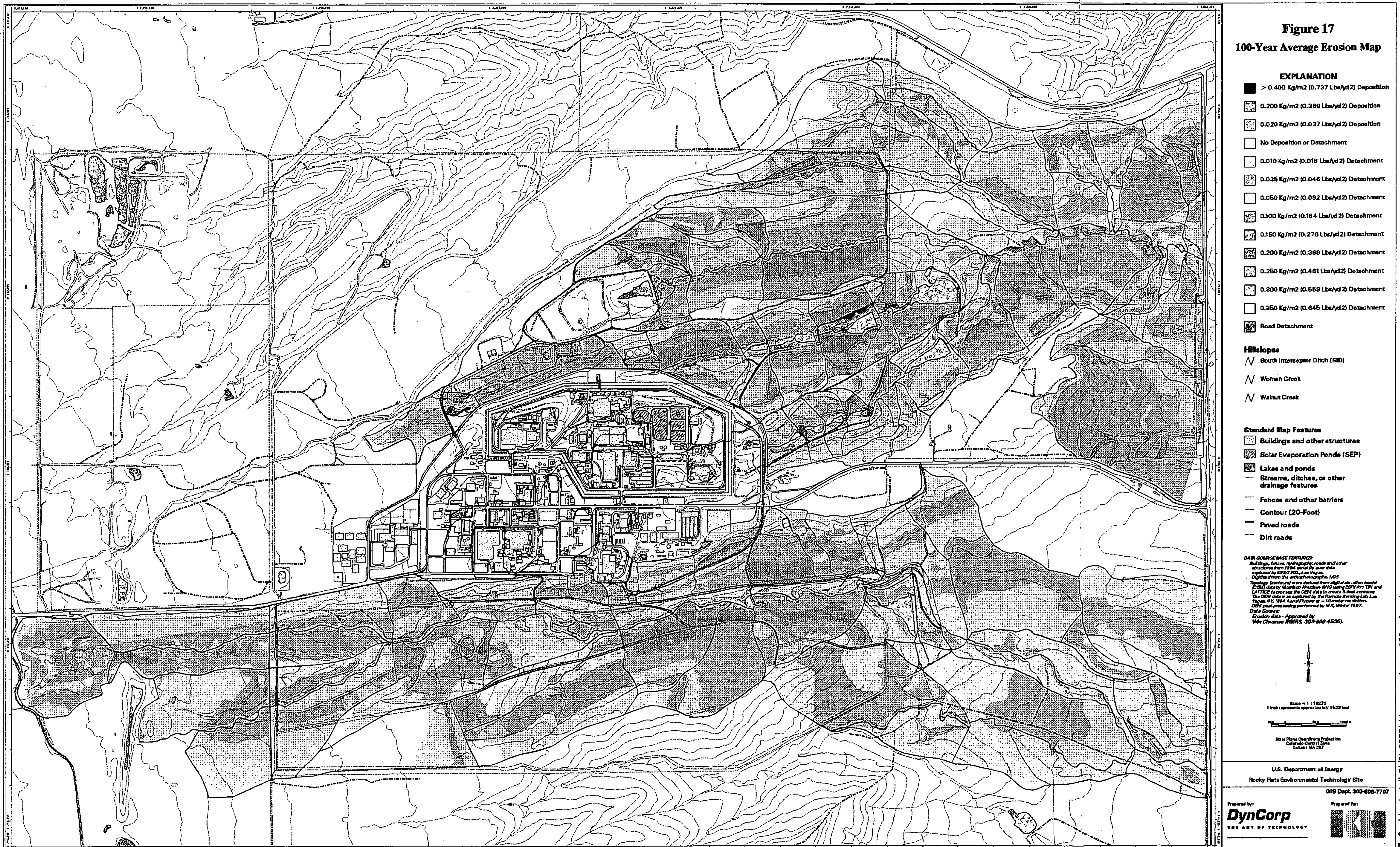


Figure 17
100-Year Average Erosion Map

Figure 13. Schematic Diagram of Walnut Creek HEC-6T Sediment Transport Model

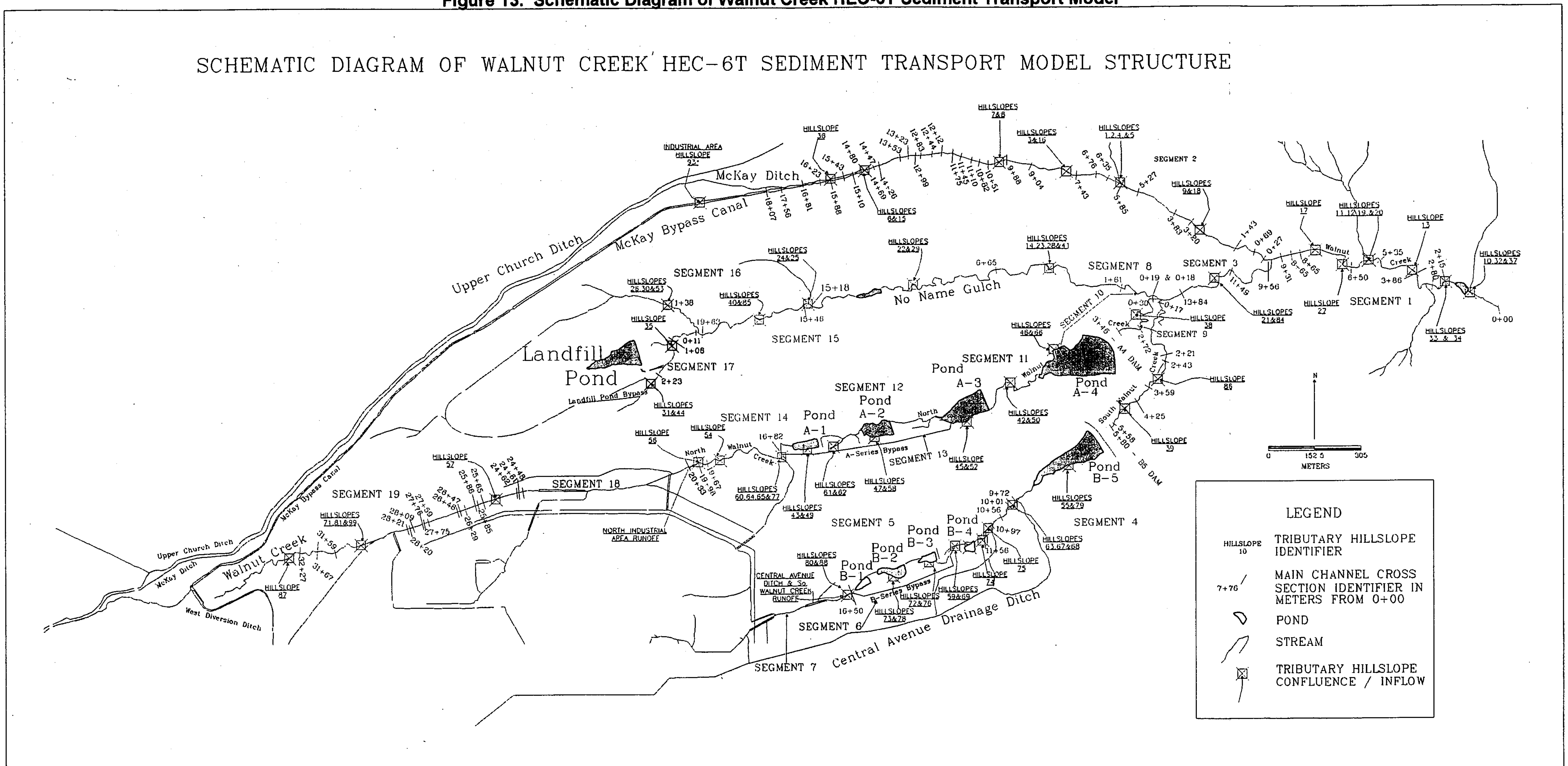


Figure 12. Schematic Diagram of Woman Creek and Mower Ditch HEC-6T Sediment Transport Models

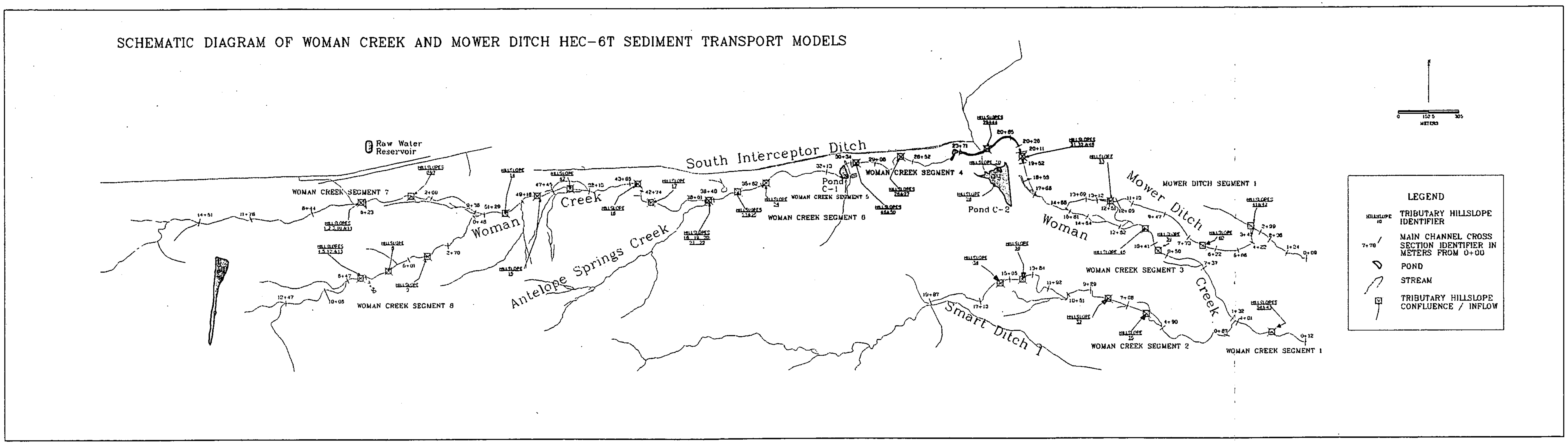
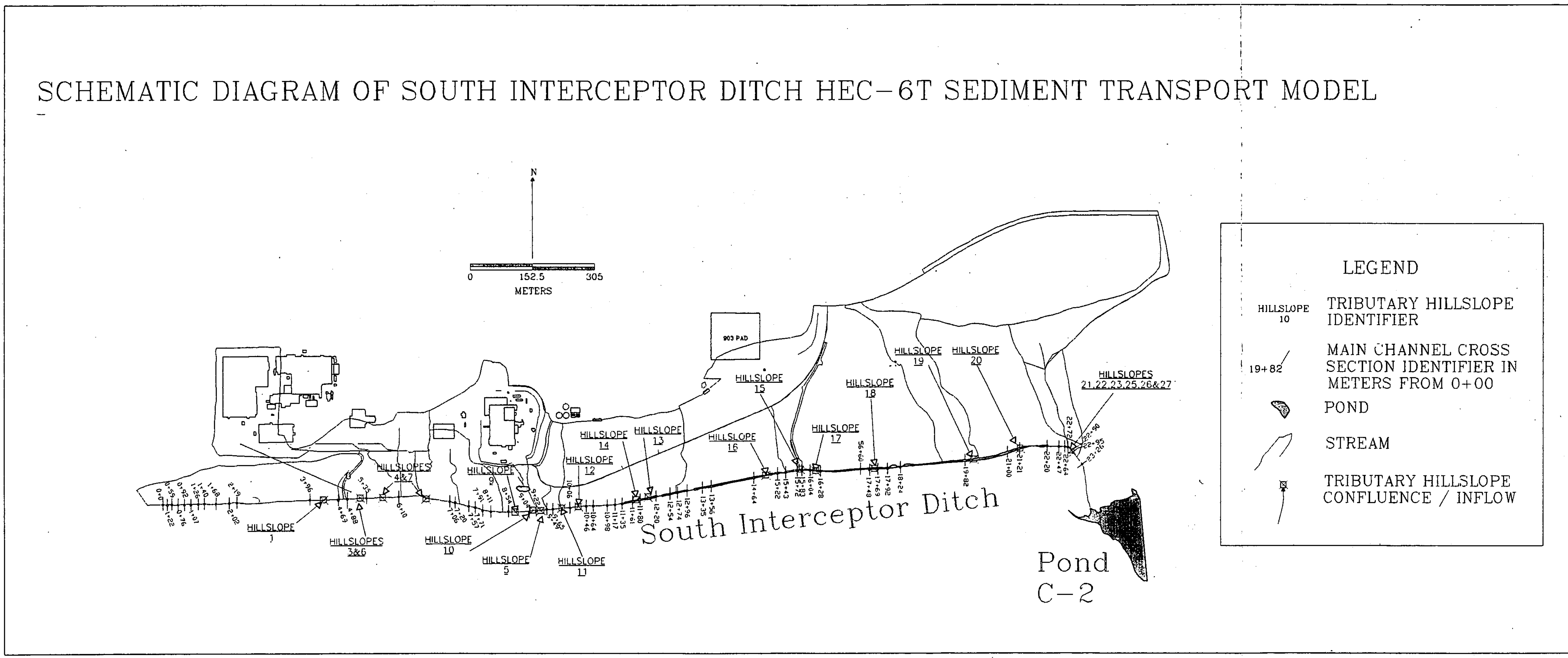


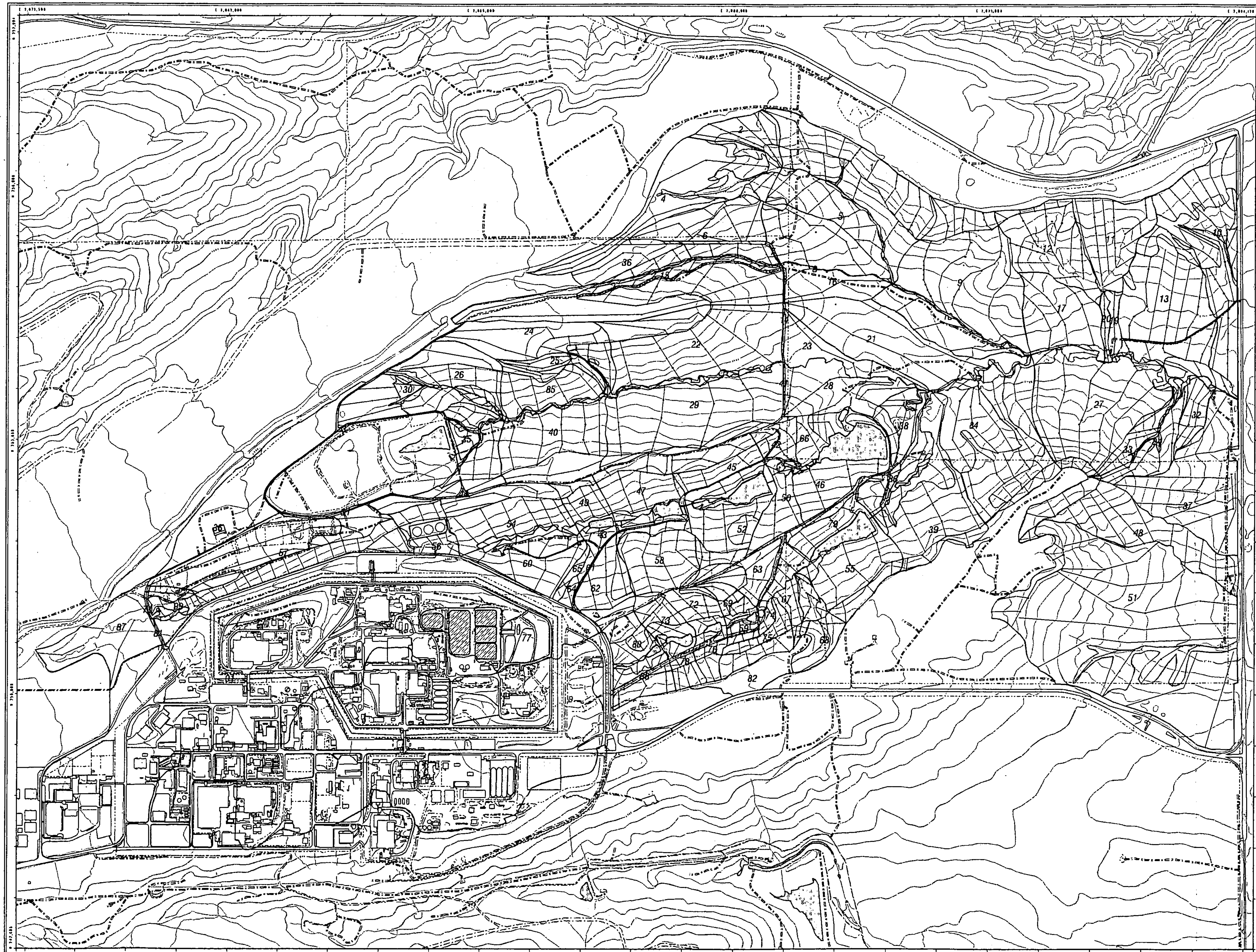
Figure 11. Schematic Diagram of South Interceptor Ditch HEC-6T Sediment Transport Model



Rocky Flats Environmental Technology Site

Figure 9

Walnut Creek Watershed Hillslopes Overland Flow Elements and Slope Transects



EXPLANATION

Hillslope Features

- Slope Measurement
- Hillslope Boundary
- OFE Boundary
- Slope Transect

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (20-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Data Source:
Hillslope, OFE, Transect data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 13580
1 inch represents approximately 1133 feet

250 0 500 1000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

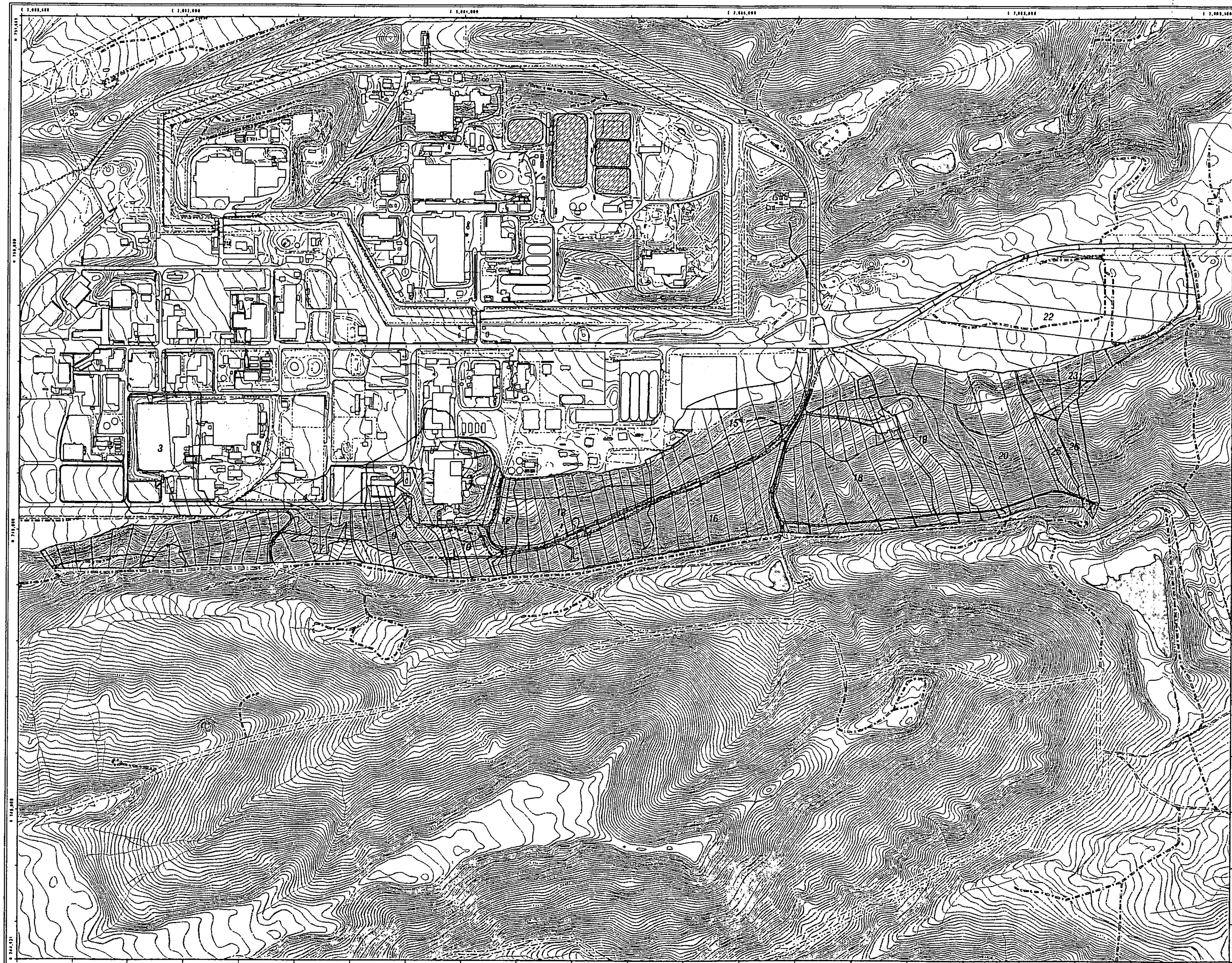
Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: actinide/walnut/walnut_hillslopes.aml

July 06, 2000

NT_Svr w:/projects/fy2k/actinide/walnut/walnut_hillslopes.aml



Rocky Flats Environmental Technology Site

Figure 8

South Interceptor Ditch Hillslopes Overland Flow Elements and Slope Transects

EXPLANATION

Hillslope Features

- Slope Measurement
- Hillslope Boundary
- OFE Boundary
- Slope Transect

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (2-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 2-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Data Source:
Hillslope, OFE, Transect data - Approved by Win Chromec (RMRS, 303-966-4535).

N

Scale = 1 : 8690
1 inch represents approximately 724 feet

250 0 500 1000 ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
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GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

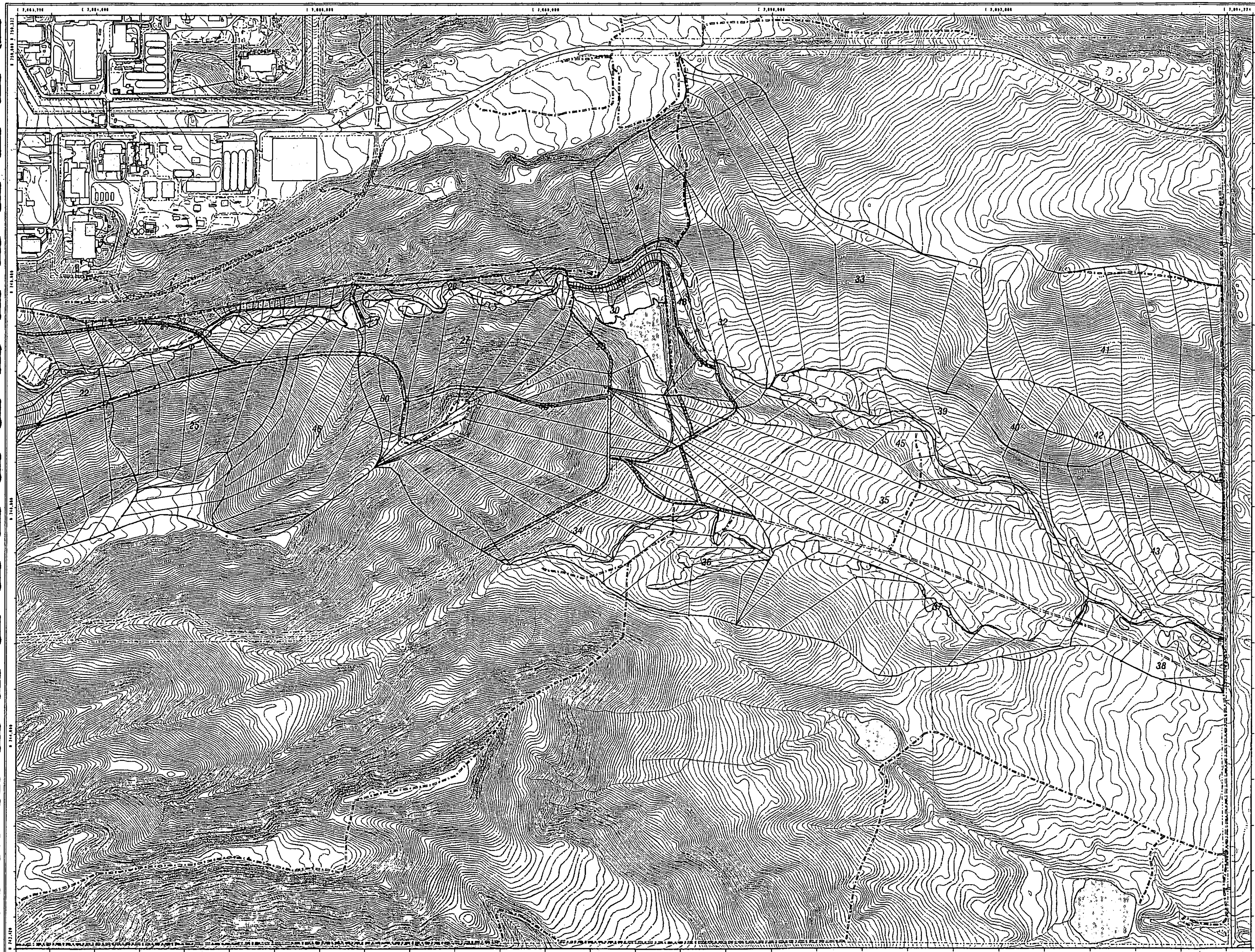
Prepared for:

MAP ID: actinide/sid/sid_hillslopes.aml

July 06, 2000

NT_Svr w:/projects/fy2k/actinide/sid/sid_hillslopes.aml

116



Rocky Flats Environmental Technology Site

Figure 7b

Woman Creek Watershed Hillslopes Overland Flow Elements and Slope Transects

Eastern Tile

EXPLANATION

Hillslope Features

- Slope Measurement
- Hillslope Boundary
- OFE Boundary
- Slope Transect

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (2-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 2-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Data Source:
Hillslope, OFE, Transect data - Approved by Win Chromec (RMRS, 303-966-4535).

N

Scale = 1 : 10160
1 inch represents approximately 847 feet

250 0 500 1000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

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GIS Dept. 303-966-7707

Prepared by:
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Prepared for:

MAP ID: actinide/woman/woman_hillslopes_east.aml

July 06, 2000

NT_Srv w:/projects/fy2k/actinide/woman/woman_hillslopes_east.aml

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Rocky Flats Environmental Technology Site

Figure 7a

Woman Creek Watershed Hillslopes Overland Flow Elements and Slope Transects

Western Tile

EXPLANATION

Hillslope Features

- Slope Measurement
- Hillslope Boundary
- OFE Boundary
- Slope Transect

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (2-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 2-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.
Data Source:
Hillslope, OFE, Transect data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 10780
1 inch represents approximately 898 feet

250 0 500 1000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

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GIS Dept. 303-966-7707

Prepared by:
DynCorp
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Prepared for:

MAP ID: actinide/woman/woman_hillslopes_west.aml

July 06, 2000

NT_Svr w:/projects/fy2k/actinide/woman/woman_hillslopes_west.aml

114

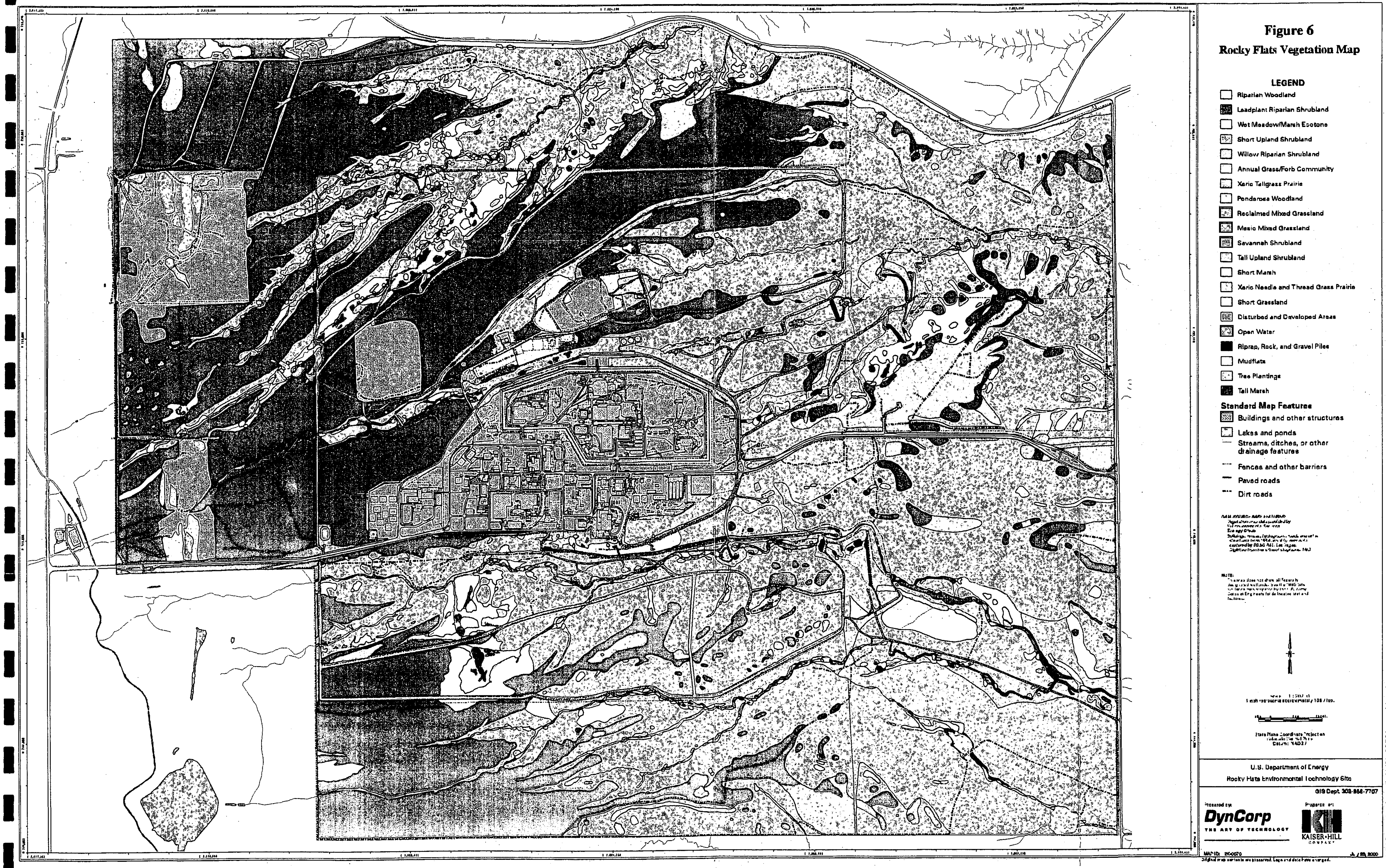

Figure 6
Rocky Flats Vegetation Map

13

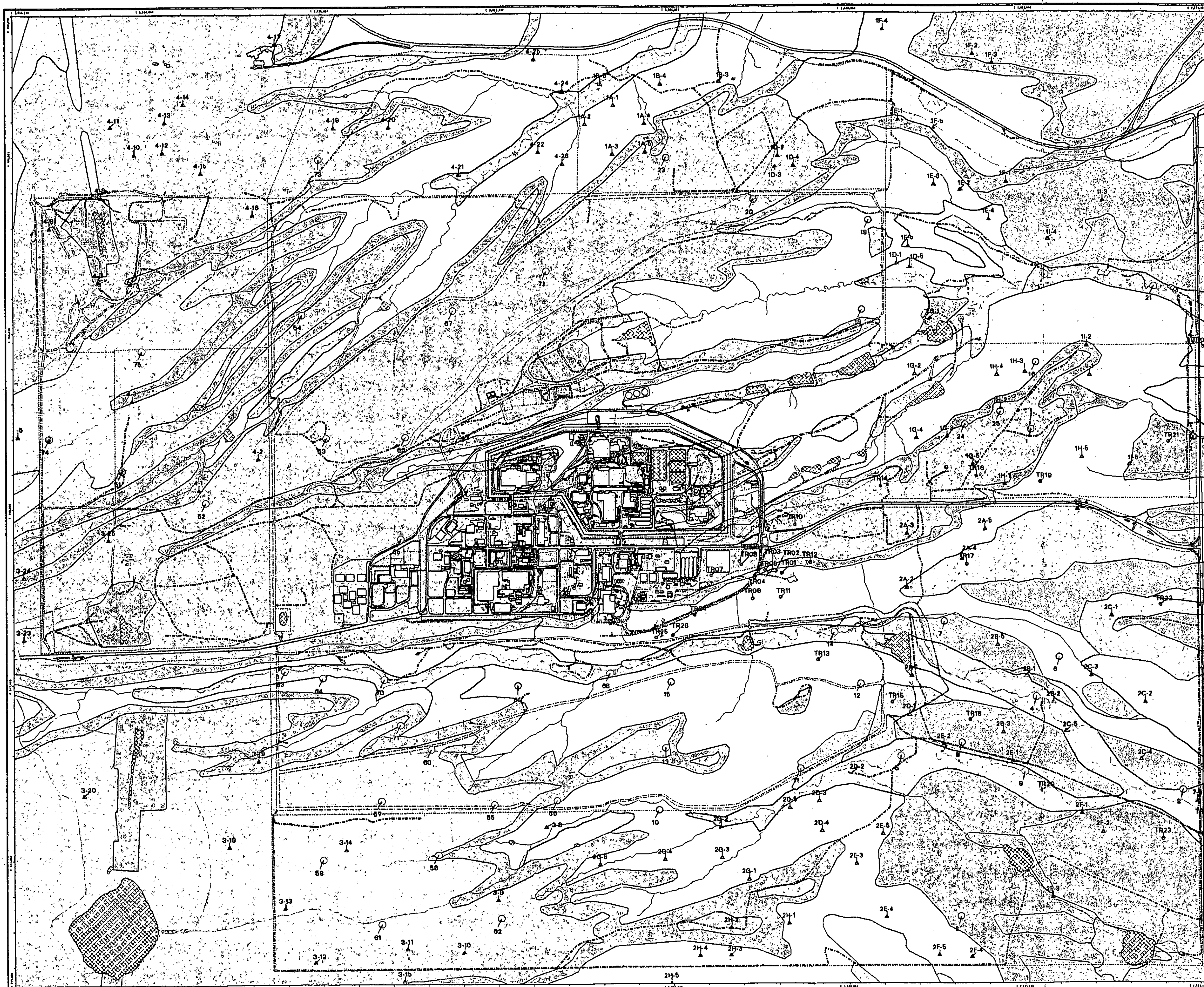

Figure 5
Rocky Flats Soils Map with Hydraulic Conductivity Measurement and Soil Sampling Locations

EXPLANATION

Sampling Features

- Tension infiltrometer sampling location
- Soil Pit Location
- CDPHE Samples

Soils

- Denver clay loam, 2 - 5%
- Denver clay loam, 5 - 9%
- Denver-Kutch clay loam, 5 - 9%
- Denver-Kutch clay loam, 9 - 15%
- Denver-Kutch-Midway clay loam, 9 - 25%
- Englewood clay loam, 0 - 2%
- Englewood clay loam, 2 - 5%
- Flatirons cobbly sandy loam, 0 - 3%
- Flatirons stoney sandy loam, 0 - 5%
- Haverson loam, 0 - 3%
- Leyden-Primen-Standley cobbly clay loams, 15 - 50%
- McClave clay loam, 0 - 3%
- Midway clay loam, 9 - 30%
- Nederland very cobbly sandy loam, 15 - 50%
- Nunn clay loam, 0 - 2%
- Nunn clay loam, 2 - 5%
- Pits, gravel
- Rock outcrop, Sedimentary
- Standley-Nunn gravelly clay loam, 0 - 5%
- Valmont clay loam, 0 - 3%
- Valmont-Nederland very cobbly sandy loam, 0 - 3%
- Willowman-Leyden cobbly loam, 9 - 30%
- Yoder Ferlant-Midway complex, 15 - 60%

Standard Map Features

- Buildings and other structures
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Soils data from the US Soil Conservation Service. Uncertified Golden Area Soil Survey - 1980.
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Scale = 1 : 20240
1 inch represents approximately 1687 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
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GIS Dept. 303-966-7707

Prepared by: DynCorp THE ART OF TECHNOLOGY

Prepared for: KAISER-HILL COMPANY

MAP ID: 99-0402

July 28, 2000

Original map contents are preserved. Logo and date have changed.

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112

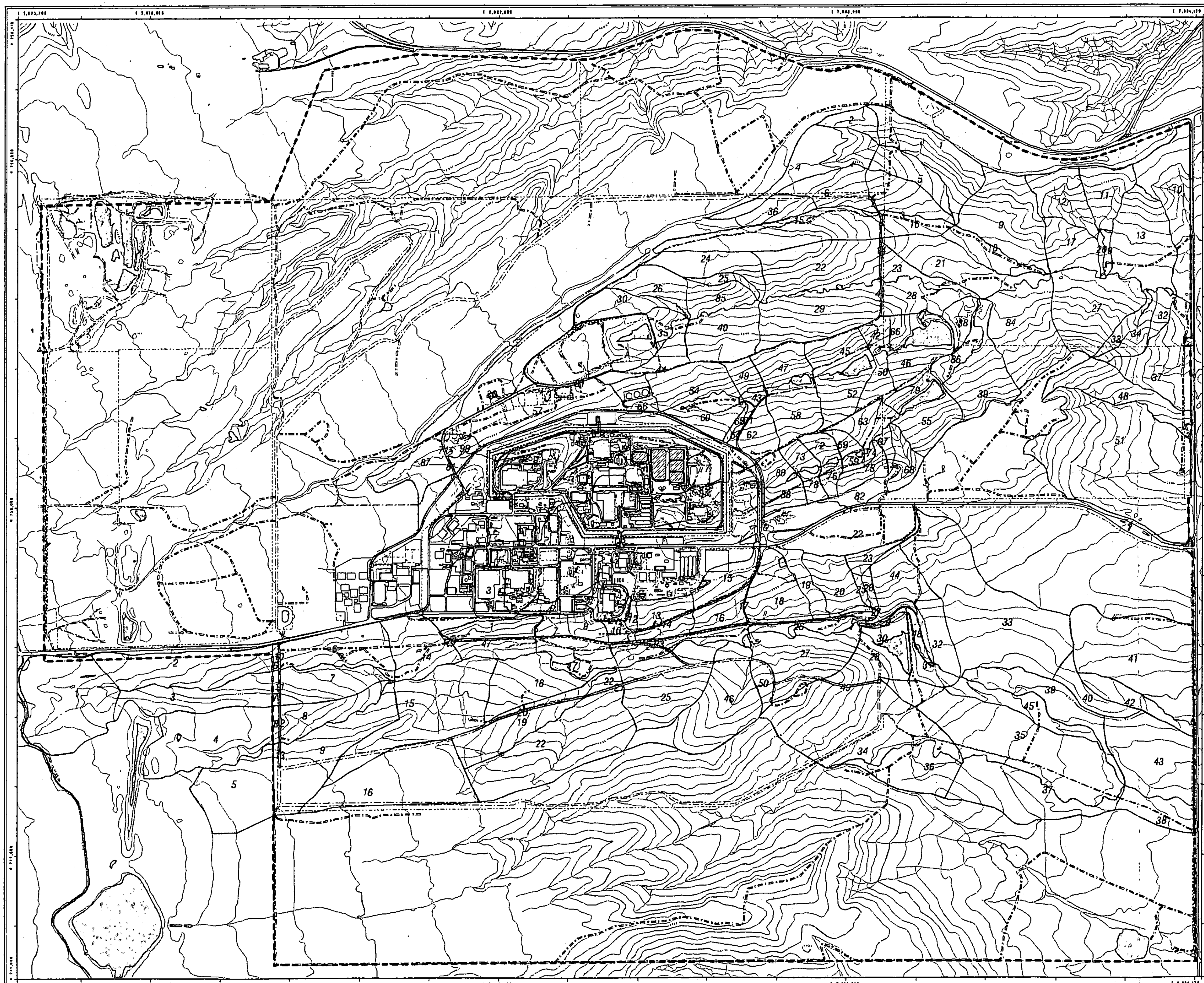

Figure 4

WEPP Model Hillslopes

EXPLANATION

Hillslope Boundaries

- Woman Creek Watershed Hillslopes
- South Interceptor Ditch Hillslopes
- Walnut Creek Watershed Hillslopes

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (20-Foot)
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.
Data Source:
Hillslope Data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 21330
1 inch represents approximately 1778 feet

500 0 1000 2000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: actinide/all/hillslopes_all.aml

July 06, 2000

NT Svr w:/projects/fy2k/actinide/all/hillslopes_all.aml

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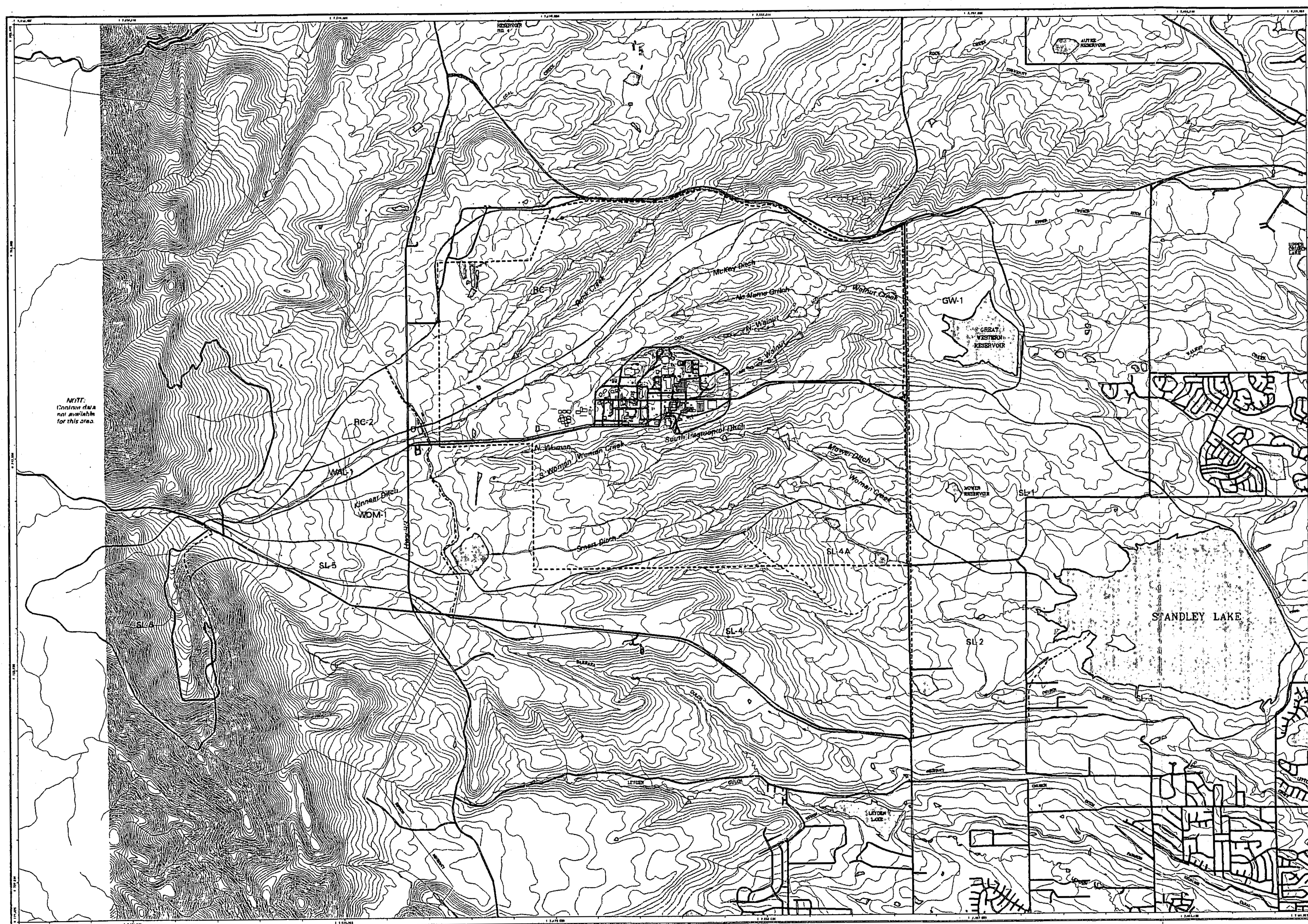

Figure 1

Major Drainage Basins at Rocky Flats

EXPLANATION

Major Drainage Basin Boundary

Sub-Basin Boundary

Areas of Sub-basins

Rock Creek 1 - 1662.8 Acres

Rock Creek 2 210.5 Acres

Walnut Creek 1 - 143.2 Acres

Woman Creek 1 563.7 Acres

Great Western 1 - 584.0 Acres

Standley Lake 1 1537.2 Acres

Standley Lake 2 - 838.4 Acres

Standley Lake 3 - 428.8 Acres

Standley Lake 4 - 1806.3 Acres

Standley Lake 4A - 628.4 Acres

Standley Lake 5 - 380.7 Acres

Standley Lake 6 - 812.2 Acres

Standard Map Features

Buildings and other structures

Solar Evaporation Ponds (SEP)

Lakes and ponds

Streams, ditches, or other drainage features

Rocky Flats boundary

DATA SOURCE BASE FEATURES:

Digitized from the orthophotographs. 1/05

Wm Chromec (RMRS, 303-966-4535)

Datum: NAD27

U.S. Department of Energy

Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:

DynCorp

THE ART OF TECHNOLOGY

Prepared for:

NT_Svr w:/projects/fy2k/2k-0069/basins.aml

108

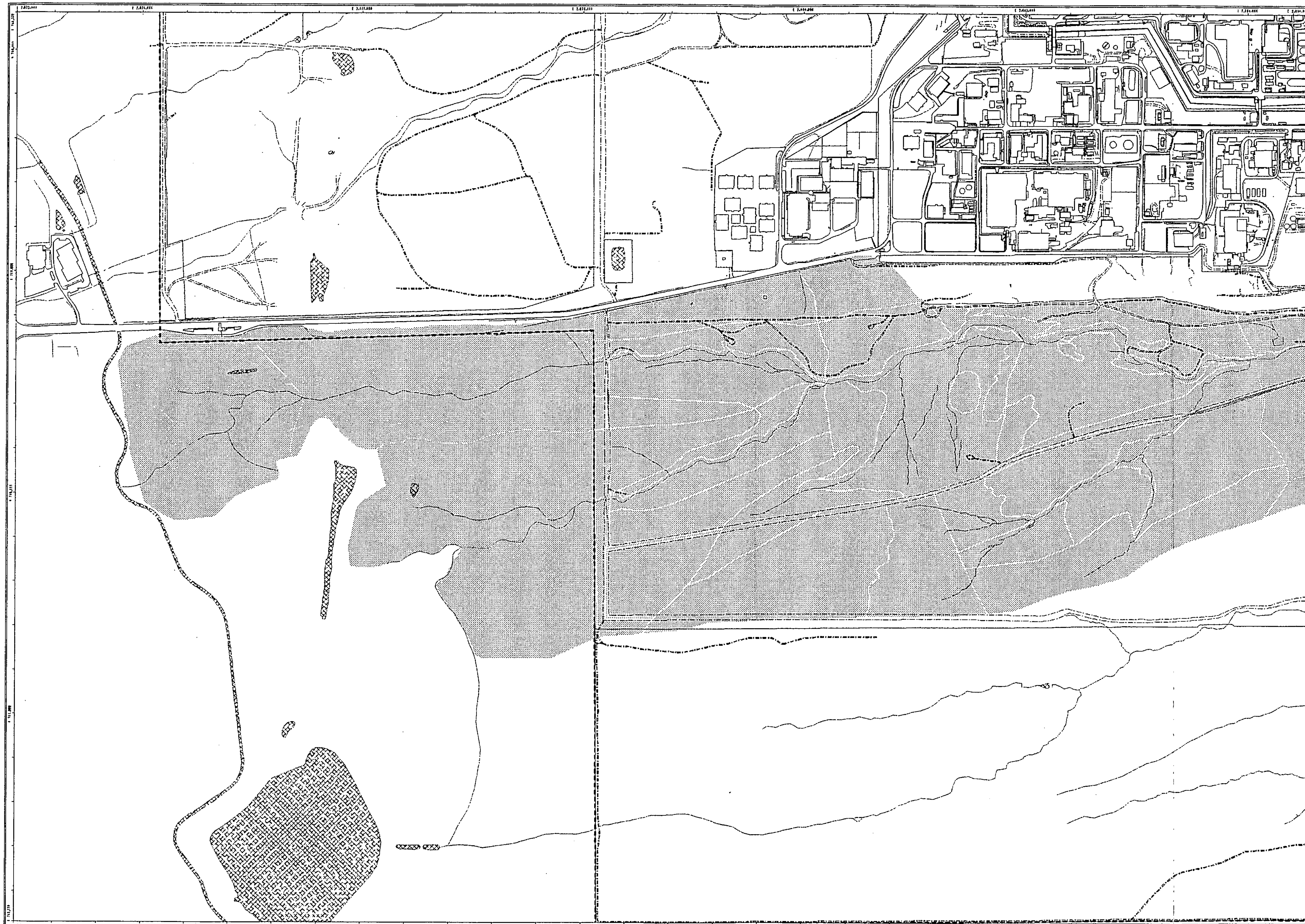

Figure 33

100-Year Average Am-241 Mobility Map

Woman Creek

Western Tile

EXPLANATION

- < = 10 pCi/m2 (0.929 pCi/ft2)
- < = 50 pCi/m2 (4.645 pCi/ft2)
- < = 100 pCi/m2 (9.290 pCi/ft2)
- < = 250 pCi/m2 (23.226 pCi/ft2)
- < = 500 pCi/m2 (46.452 pCi/ft2)
- < = 750 pCi/m2 (69.677 pCi/ft2)
- < = 1000 pCi/m2 (92.903 pCi/ft2)
- < = 2500 pCi/m2 (232.258 pCi/ft2)
- < = 5000 pCi/m2 (464.515 pCi/ft2)
- > 5000 pCi/m2 (464.515 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas.
Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 10500
1 inch represents approximately 883 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0065/woman_west_am_mob_m2_100avg.aml

July 06, 2000

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143

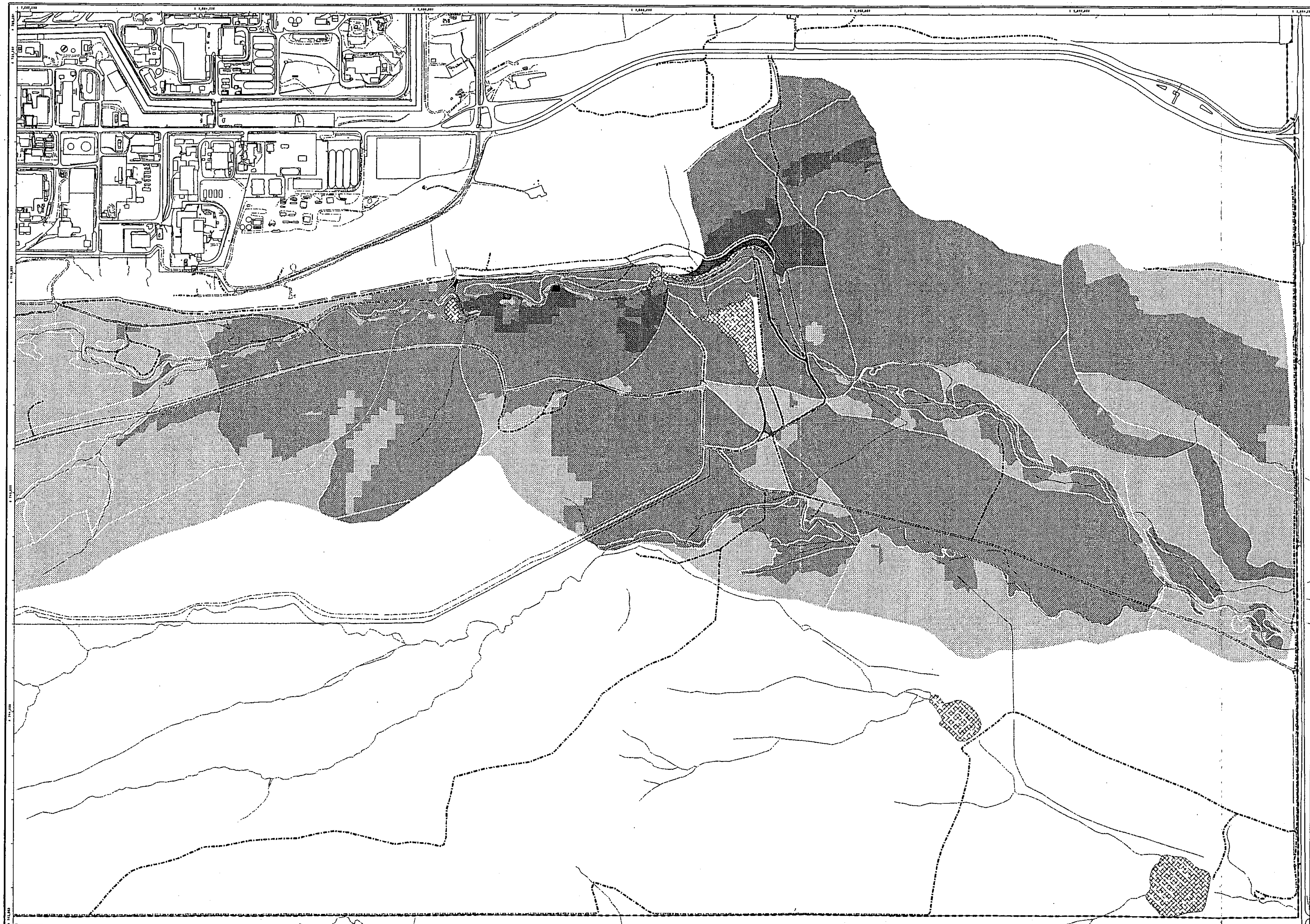


Figure 32

100-Year Average Pu-239 Mobility Map

Woman Creek

Eastern Tile

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0065/woman_east_pu_mob_m2_100avg.aml July 06, 2000

NT_Svr h:/projects/fy2k/2k-0065/woman_east_pu_mob_m2_100avg.aml

142

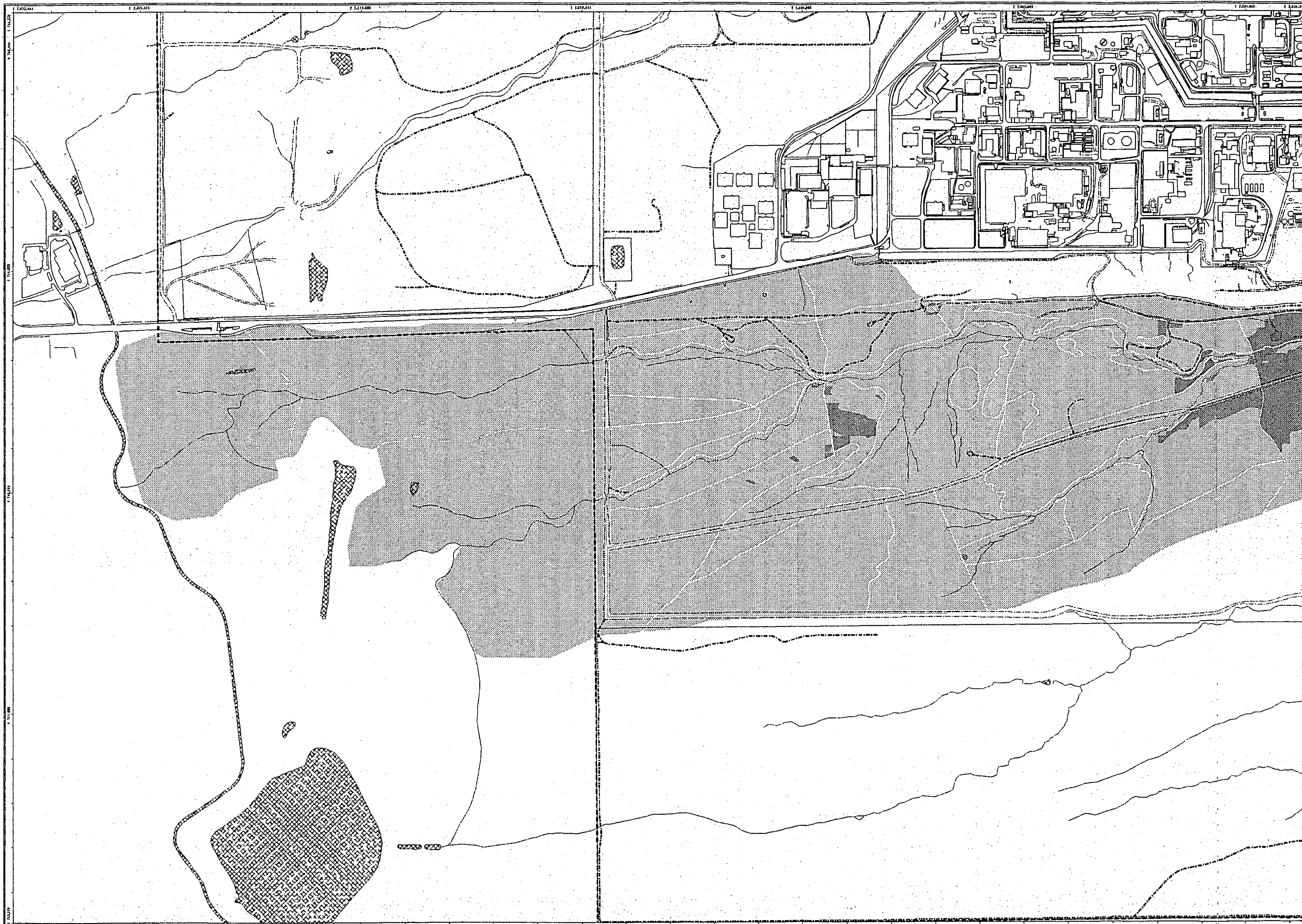


Figure 31

100-Year Average Pu-239 Mobility Map

Woman Creek

Western Tile

EXPLANATION

- < = 10 pCi/m2 (0.929 pCi/ft2)
- < = 100 pCi/m2 (9.290 pCi/ft2)
- < = 500 pCi/m2 (46.452 pCi/ft2)
- < = 1000 pCi/m2 (92.903 pCi/ft2)
- < = 2000 pCi/m2 (185.806 pCi/ft2)
- < = 3000 pCi/m2 (278.709 pCi/ft2)
- < = 4000 pCi/m2 (371.612 pCi/ft2)
- < = 5000 pCi/m2 (464.515 pCi/ft2)
- < = 10000 pCi/m2 (929.030 pCi/ft2)
- < = 25000 pCi/m2 (2322.576 pCi/ft2)
- > 25000 pCi/m2 (2322.576 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 10600
1 inch represents approximately 883 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

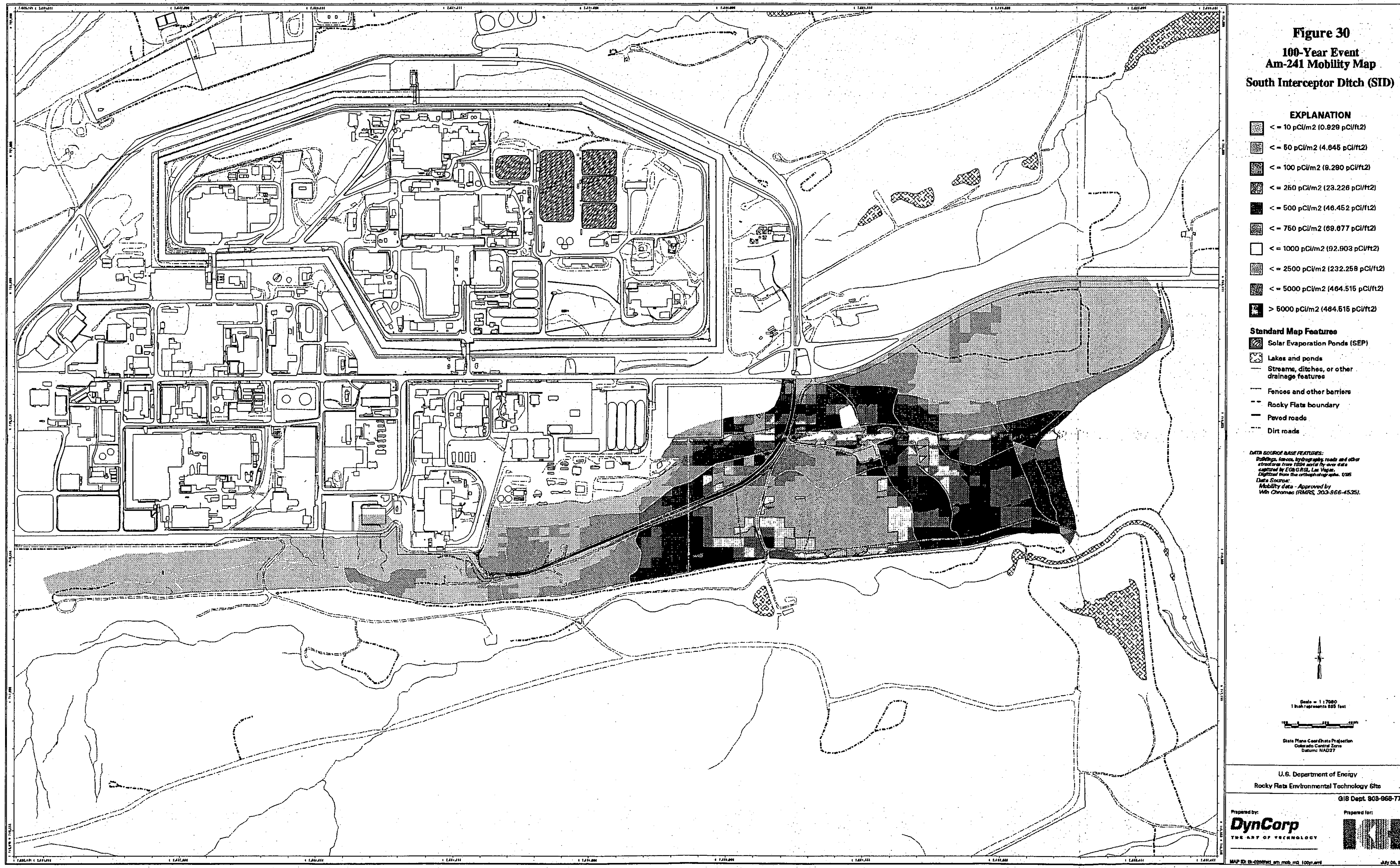
Prepared for:

MAP ID: 2k-0065/woman_west_pu_mob_m2_100avg.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0065/woman_west_pu_mob_m2_100avg.aml

141



NT_Svr h:/projects/fy2k/2k-0268/sid_am_mob_m2_100yr.aml

140

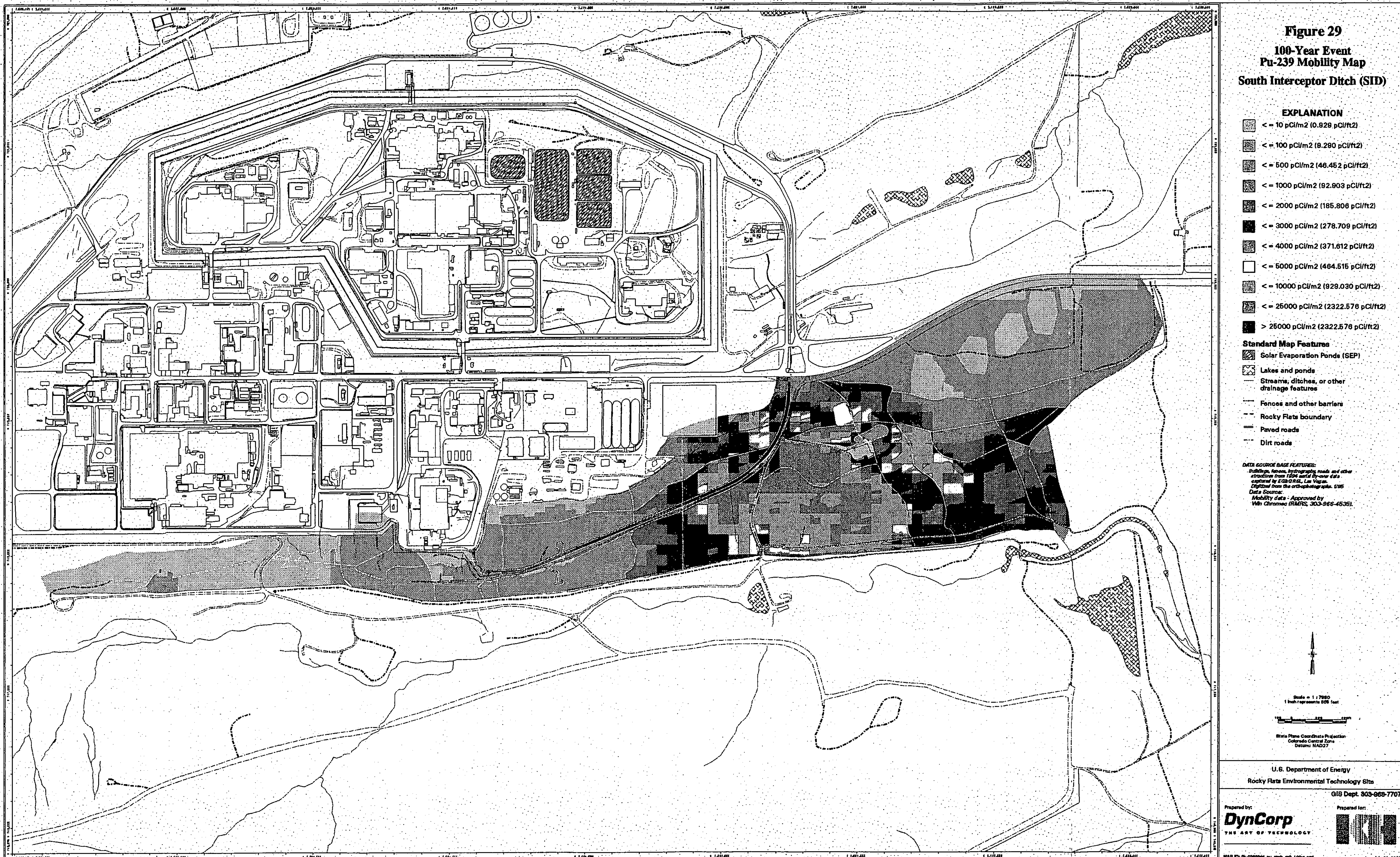


Figure 29
100-Year Event Pu-239 Mobility Map
South Interceptor Ditch (SID)

NT_Svr h:/projects/fy2k/2k-0266/sid_pu_mob_m2_100yr.aml

139

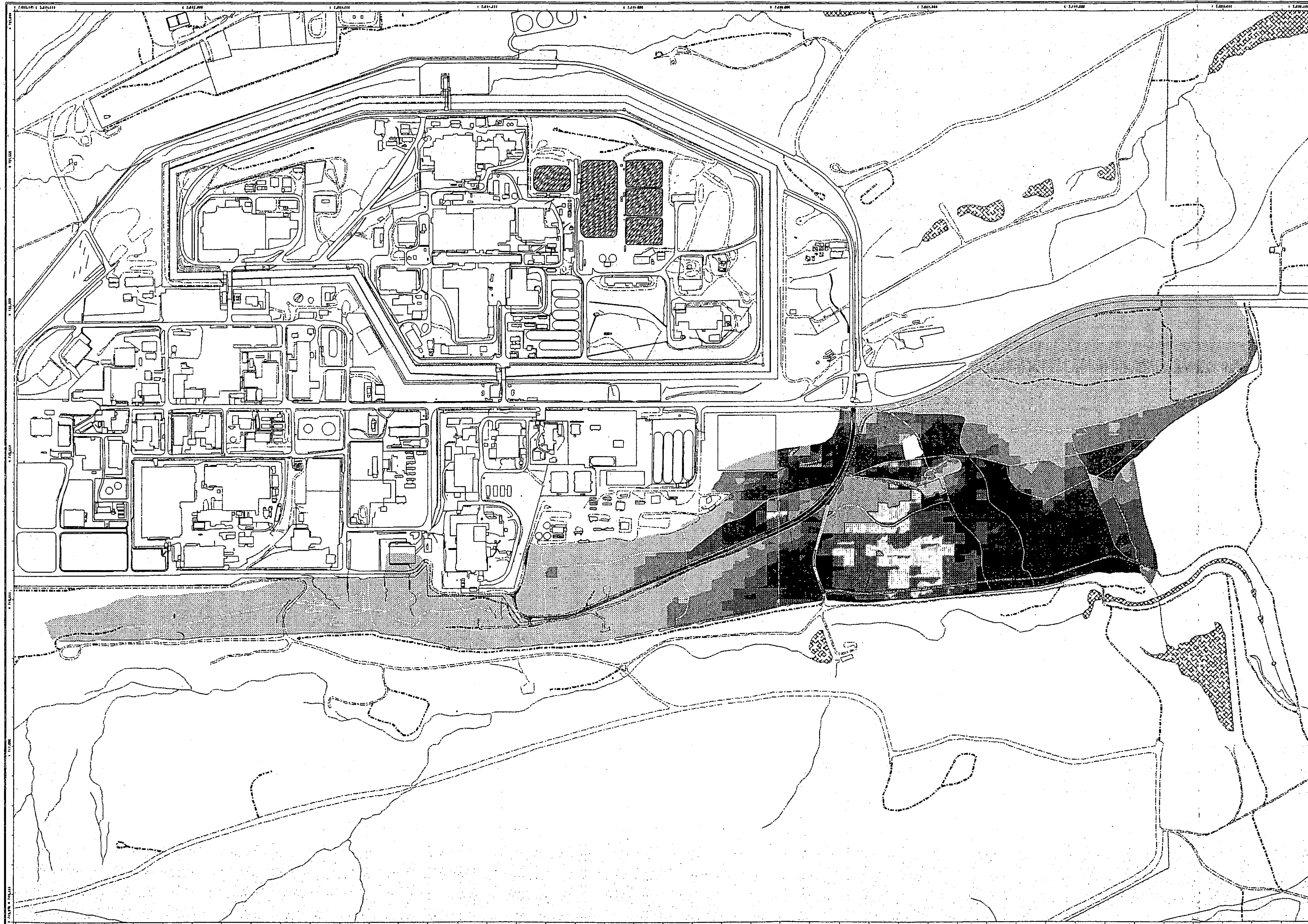


Figure 28

100-Year Average
Am-241 Mobility Map
South Interceptor Ditch (SID)

EXPLANATION

- <= 10 pCi/m2 (0.929 pCi/ft2)
- <= 50 pCi/m2 (4.645 pCi/ft2)
- <= 100 pCi/m2 (9.290 pCi/ft2)
- <= 250 pCi/m2 (23.226 pCi/ft2)
- <= 500 pCi/m2 (46.452 pCi/ft2)
- <= 750 pCi/m2 (69.677 pCi/ft2)
- <= 1000 pCi/m2 (92.903 pCi/ft2)
- <= 2500 pCi/m2 (232.258 pCi/ft2)
- <= 5000 pCi/m2 (464.515 pCi/ft2)
- > 5000 pCi/m2 (464.515 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4536).

Scale = 1 : 7080
1 inch represents 565 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0264/sid_am_mob_m2_100avg.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0264/sid_am_mob_m2_100avg.aml

138

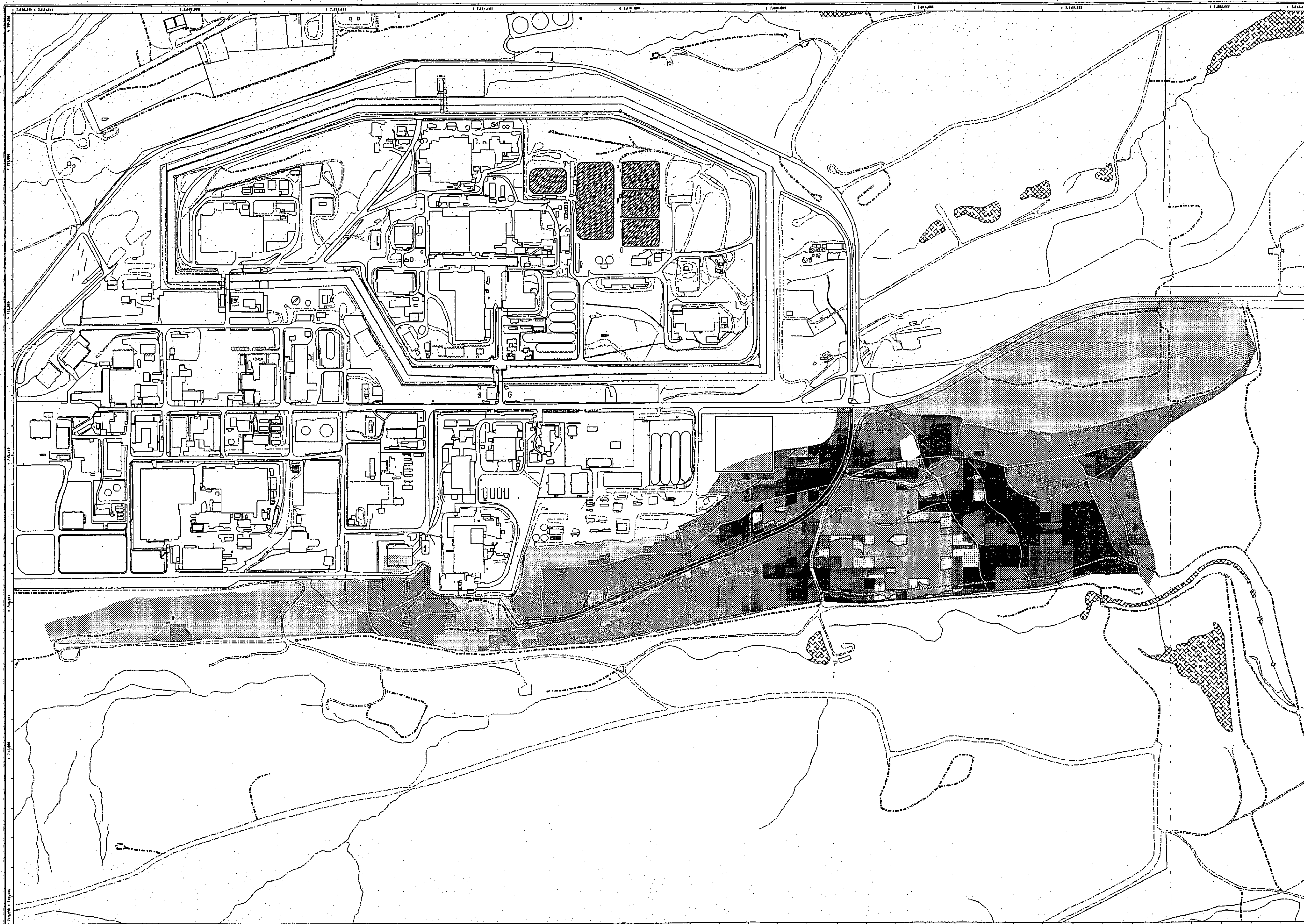


Figure 27

100-Year Average Pu-239 Mobility Map

South Interceptor Ditch (SID)

EXPLANATION

- < = 10 pCi/m2 (0.929 pCi/ft2)
- < = 100 pCi/m2 (9.290 pCi/ft2)
- < = 500 pCi/m2 (46.452 pCi/ft2)
- < = 1000 pCi/m2 (92.903 pCi/ft2)
- < = 2000 pCi/m2 (185.806 pCi/ft2)
- < = 3000 pCi/m2 (278.709 pCi/ft2)
- < = 4000 pCi/m2 (371.612 pCi/ft2)
- < = 5000 pCi/m2 (464.515 pCi/ft2)
- < = 10000 pCi/m2 (929.030 pCi/ft2)
- < = 25000 pCi/m2 (2322.576 pCi/ft2)
- > 25000 pCi/m2 (2322.576 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 7080
1 inch represents 665 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0264/sid_pu_mob_m2_100avg.aml

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NT_Svr h:/projects/fy2k/2k-0264/sid_pu_mob_m2_100avg.aml

137

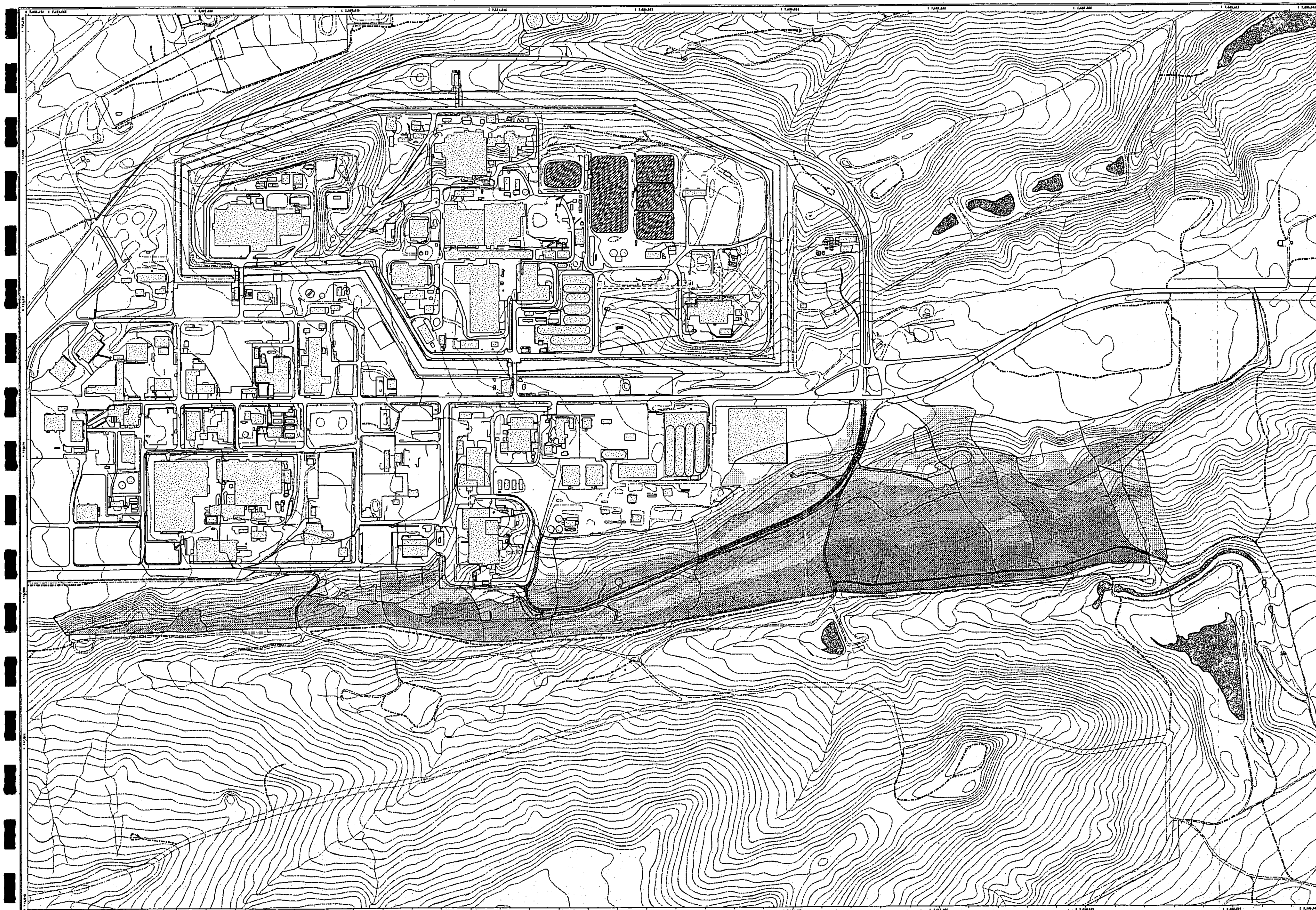


Figure 26

May 17,1995 Event Erosion Map

South Interceptor Ditch (SID)

EXPLANATION

- > 0.400 Kg/m2 (0.737 Lbs/yd2) Deposition
- 0.200 Kg/m2 (0.369 Lbs/yd2) Deposition
- 0.020 Kg/m2 (0.037 Lbs/yd2) Deposition
- No Deposition or Detachment
- 0.010 Kg/m2 (0.018 Lbs/yd2) Detachment
- 0.025 Kg/m2 (0.046 Lbs/yd2) Detachment
- 0.050 Kg/m2 (0.092 Lbs/yd2) Detachment
- 0.100 Kg/m2 (0.184 Lbs/yd2) Detachment
- 0.150 Kg/m2 (0.276 Lbs/yd2) Detachment
- 0.200 Kg/m2 (0.369 Lbs/yd2) Detachment
- 0.250 Kg/m2 (0.461 Lbs/yd2) Detachment
- 0.300 Kg/m2 (0.553 Lbs/yd2) Detachment
- 0.350 Kg/m2 (0.645 Lbs/yd2) Detachment
- Road Detachment

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (5-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudsen (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~10 meter resolution. DEM post-processing performed by MK, Winter 1997.
Data Source:
Erosion data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 7680
1 inch represents approximately 657 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0271/sid_erosion_may17.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0271/sid_erosion_may17.aml

136

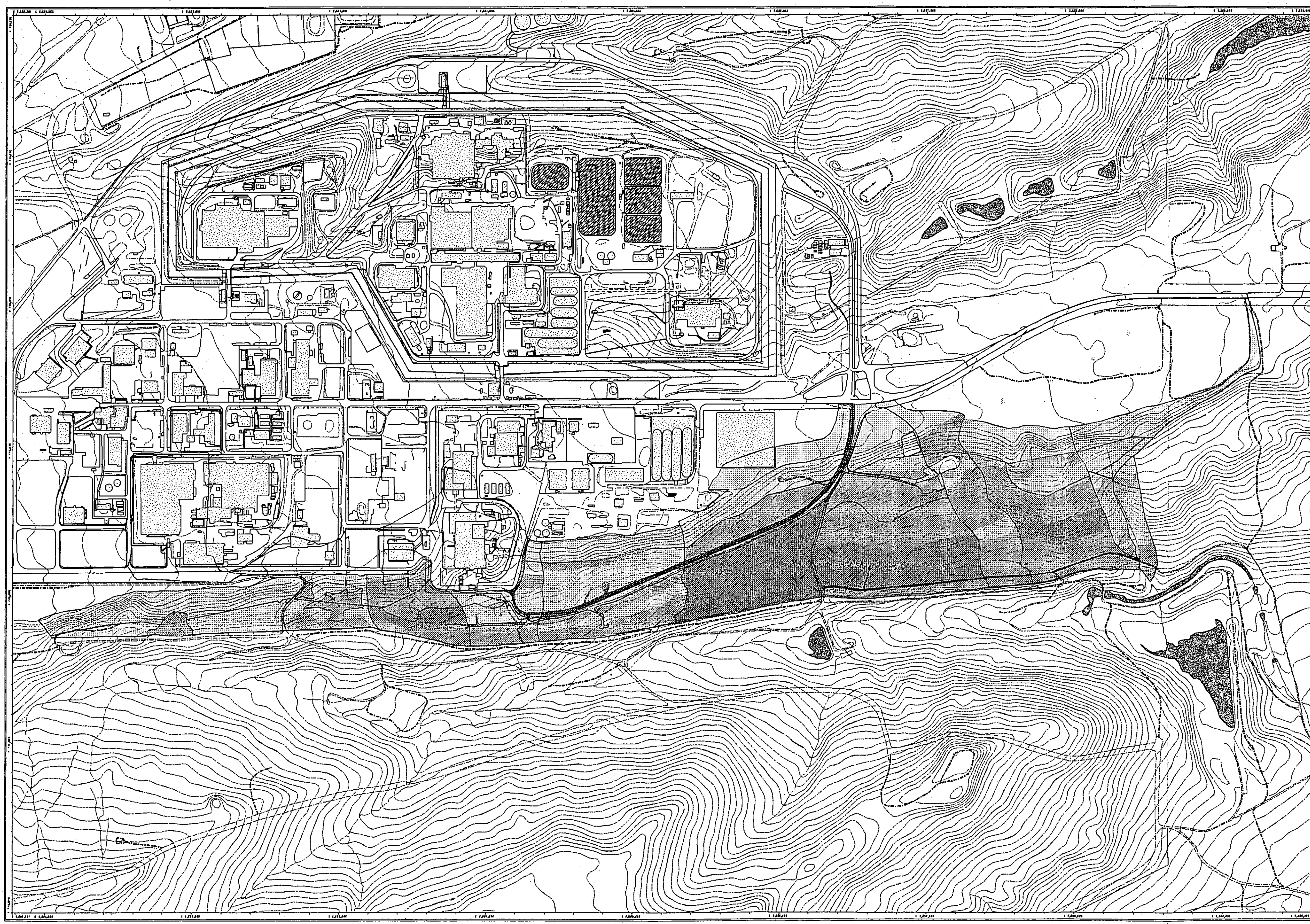


Figure 25

10-Year Event Erosion Map

South Interceptor Ditch (SID)

EXPLANATION

- > 0.400 Kg/m2 (0.737 Lbs/yd2) Deposition
- 0.200 Kg/m2 (0.369 Lbs/yd2) Deposition
- 0.020 Kg/m2 (0.037 Lbs/yd2) Deposition
- No Deposition or Detachment
- 0.010 Kg/m2 (0.018 Lbs/yd2) Detachment
- 0.025 Kg/m2 (0.046 Lbs/yd2) Detachment
- 0.050 Kg/m2 (0.092 Lbs/yd2) Detachment
- 0.100 Kg/m2 (0.184 Lbs/yd2) Detachment
- 0.150 Kg/m2 (0.276 Lbs/yd2) Detachment
- 0.200 Kg/m2 (0.369 Lbs/yd2) Detachment
- 0.250 Kg/m2 (0.461 Lbs/yd2) Detachment
- 0.300 Kg/m2 (0.553 Lbs/yd2) Detachment
- 0.350 Kg/m2 (0.645 Lbs/yd2) Detachment
- Road Detachment

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (5-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudsen (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~10 meter resolution. DEM post-processing performed by MK, Winter 1997.
Data Source:
Erosion data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 7980
1 inch represents approximately 657 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

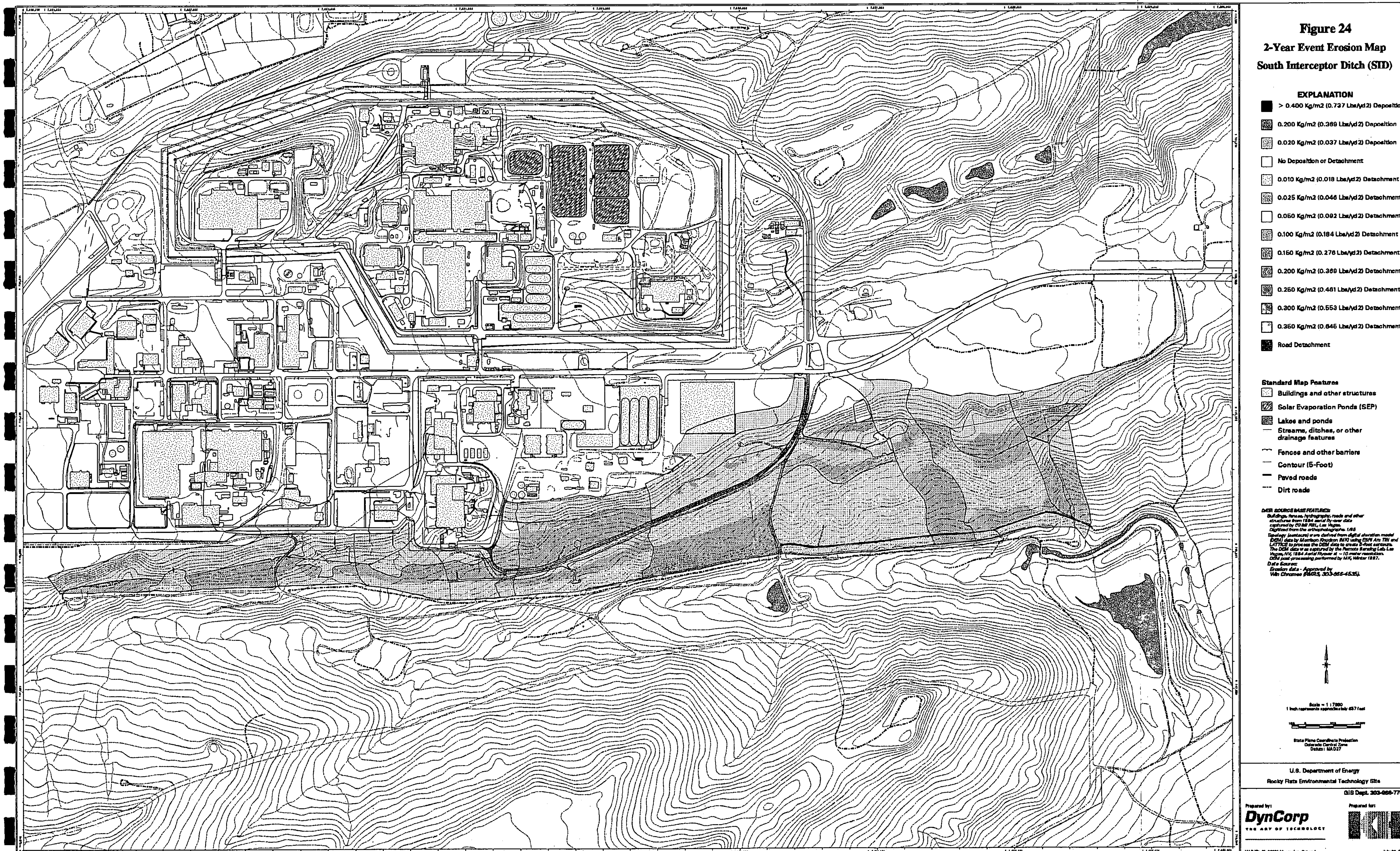
Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0287/sid_erosion_10yr.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0287/sid_erosion_10yr.aml

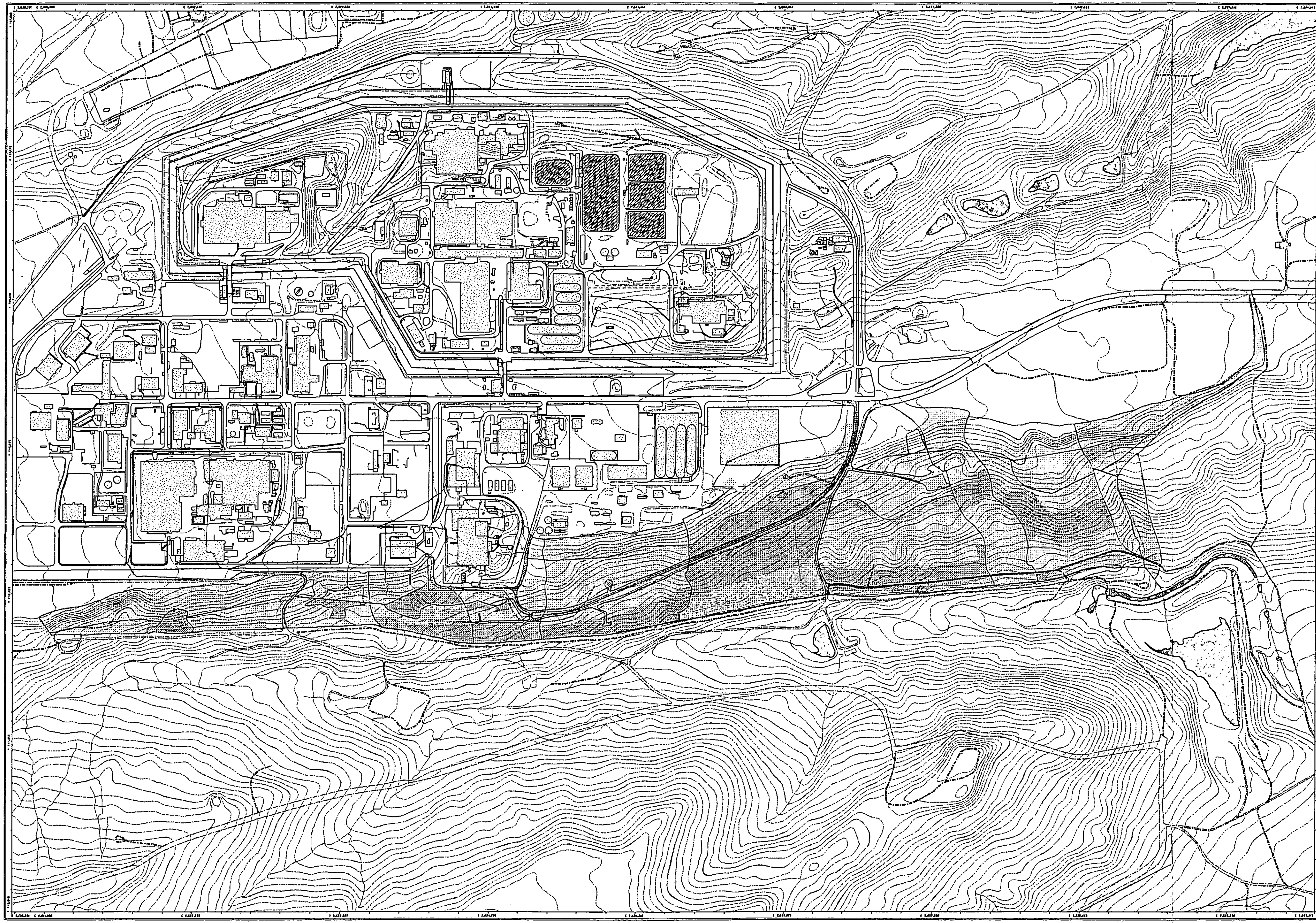


NT_Svr h:/projects/fy2k/2k-0289/sid_erosion_2yr.aml

Figure 23

2-Hour Event Erosion Map

South Interceptor Ditch (SID)



EXPLANATION

- > 0.400 Kg/m2 (0.737 Lbs/yd2) Deposition
- 0.200 Kg/m2 (0.369 Lbs/yd2) Deposition
- 0.020 Kg/m2 (0.037 Lbs/yd2) Deposition
- No Deposition or Detachment
- 0.010 Kg/m2 (0.018 Lbs/yd2) Detachment
- 0.025 Kg/m2 (0.046 Lbs/yd2) Detachment
- 0.050 Kg/m2 (0.092 Lbs/yd2) Detachment
- 0.100 Kg/m2 (0.184 Lbs/yd2) Detachment
- 0.150 Kg/m2 (0.276 Lbs/yd2) Detachment
- 0.200 Kg/m2 (0.369 Lbs/yd2) Detachment
- 0.250 Kg/m2 (0.461 Lbs/yd2) Detachment
- 0.300 Kg/m2 (0.553 Lbs/yd2) Detachment
- 0.350 Kg/m2 (0.645 Lbs/yd2) Detachment
- Road Detachment

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (5-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs, 1/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudsen (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~10 meter resolution. DEM post-processing performed by MK, Winter 1997.
Data Source:
Erosion data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 7890
1 inch represents approximately 657 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0268/sid_erosion_2hr.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0268/sid_erosion_2hr.aml

133

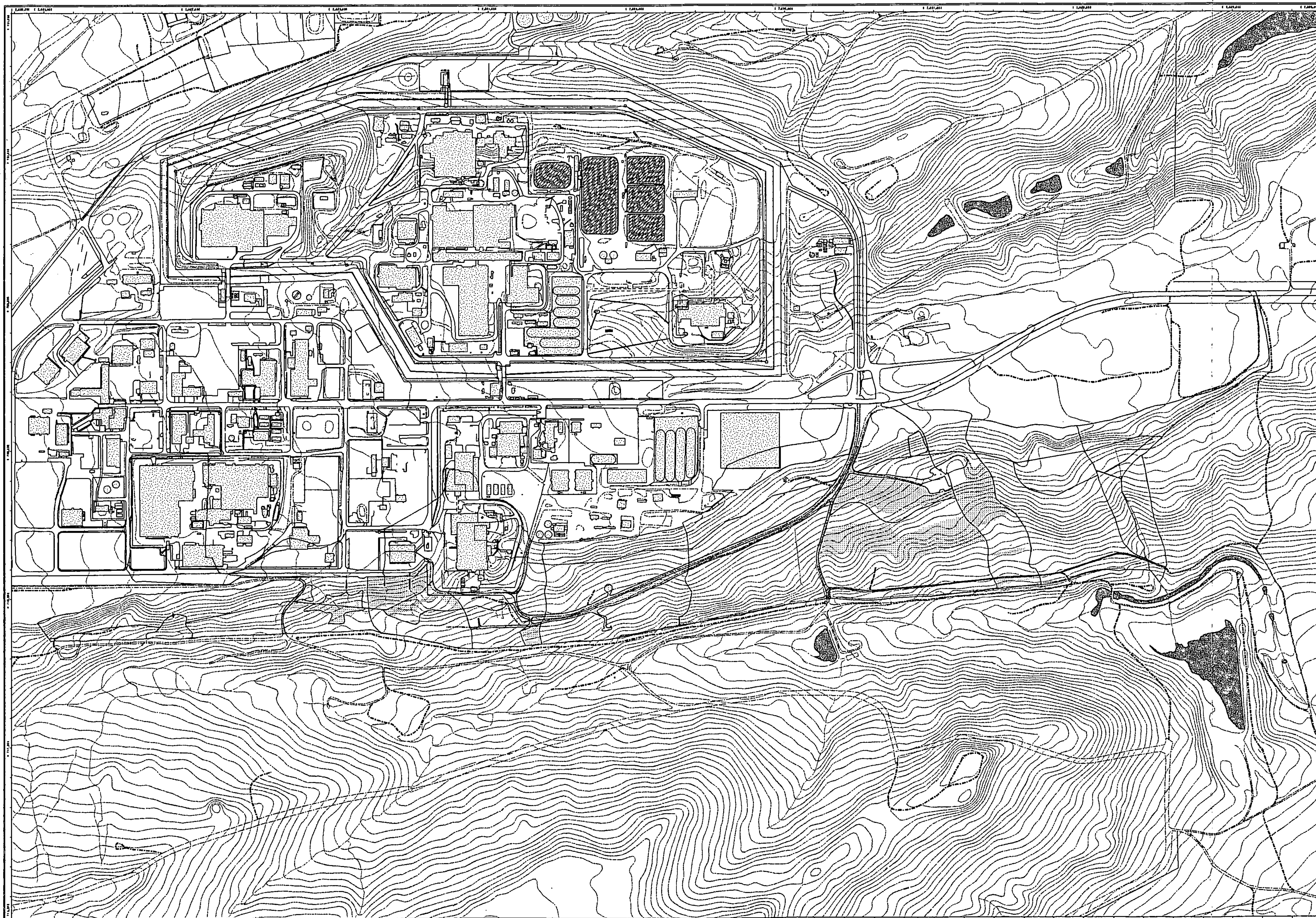


Figure 22

35 mm Event Erosion Map

South Interceptor Ditch (SID)

EXPLANATION

- > 0.400 Kg/m2 (0.737 Lbs/yd2) Deposition
- 0.200 Kg/m2 (0.369 Lbs/yd2) Deposition
- 0.020 Kg/m2 (0.037 Lbs/yd2) Deposition
- No Deposition or Detachment
- 0.010 Kg/m2 (0.018 Lbs/yd2) Detachment
- 0.025 Kg/m2 (0.046 Lbs/yd2) Detachment
- 0.050 Kg/m2 (0.092 Lbs/yd2) Detachment
- 0.100 Kg/m2 (0.184 Lbs/yd2) Detachment
- 0.150 Kg/m2 (0.276 Lbs/yd2) Detachment
- 0.200 Kg/m2 (0.369 Lbs/yd2) Detachment
- 0.250 Kg/m2 (0.461 Lbs/yd2) Detachment
- 0.300 Kg/m2 (0.553 Lbs/yd2) Detachment
- 0.350 Kg/m2 (0.645 Lbs/yd2) Detachment
- Road Detachment

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (5-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Topology (contours) were derived from digital elevation model (DEM) data by Markham Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~10 meter resolution. DEM post-processing performed by MK, Winter 1997.

Scale = 1 : 7680
1 inch represents approximately 657 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy

Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0270/sid_erosion_35mm.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0270/sid_erosion_35mm.aml

132

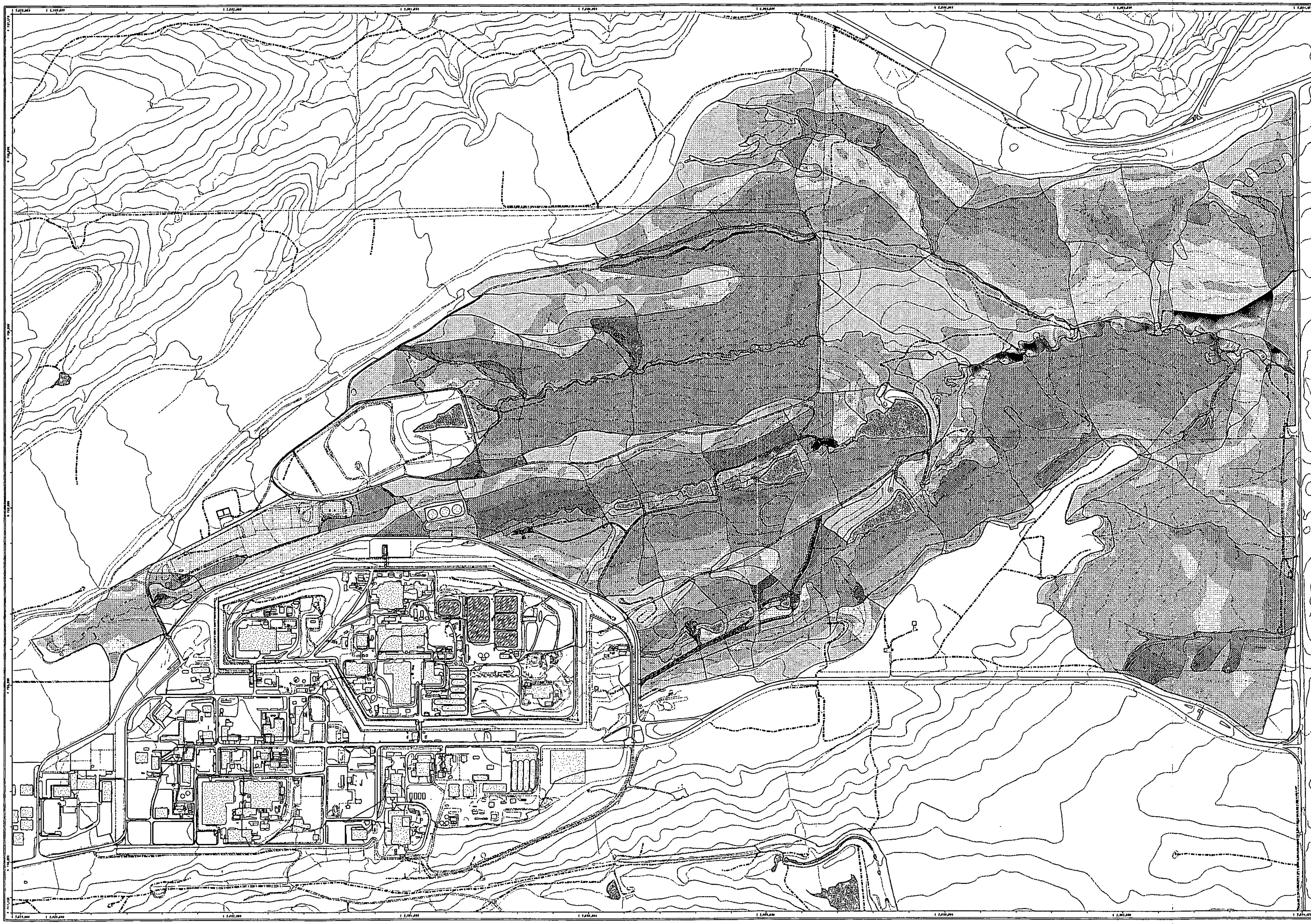


Figure 21
100-Year Event Erosion Map
Walnut Creek

EXPLANATION

- > 0.400 Kg/m2 (0.737 Lbs/yd2) Deposition
- 0.200 Kg/m2 (0.369 Lbs/yd2) Deposition
- 0.020 Kg/m2 (0.037 Lbs/yd2) Deposition
- No Deposition or Detachment
- 0.010 Kg/m2 (0.018 Lbs/yd2) Detachment
- 0.025 Kg/m2 (0.046 Lbs/yd2) Detachment
- 0.050 Kg/m2 (0.092 Lbs/yd2) Detachment
- 0.100 Kg/m2 (0.184 Lbs/yd2) Detachment
- 0.150 Kg/m2 (0.276 Lbs/yd2) Detachment
- 0.200 Kg/m2 (0.369 Lbs/yd2) Detachment
- 0.250 Kg/m2 (0.461 Lbs/yd2) Detachment
- 0.300 Kg/m2 (0.553 Lbs/yd2) Detachment
- 0.350 Kg/m2 (0.645 Lbs/yd2) Detachment
- Road Detachment

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (20-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudsen (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~10 meter resolution. DEM post-processing performed by MK, Winter 1997.
Data Source:
Erosion data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 13080
1 inch represents 1090 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0133/walnut_erosion_100yr.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0133/walnut_erosion_100yr.aml

131

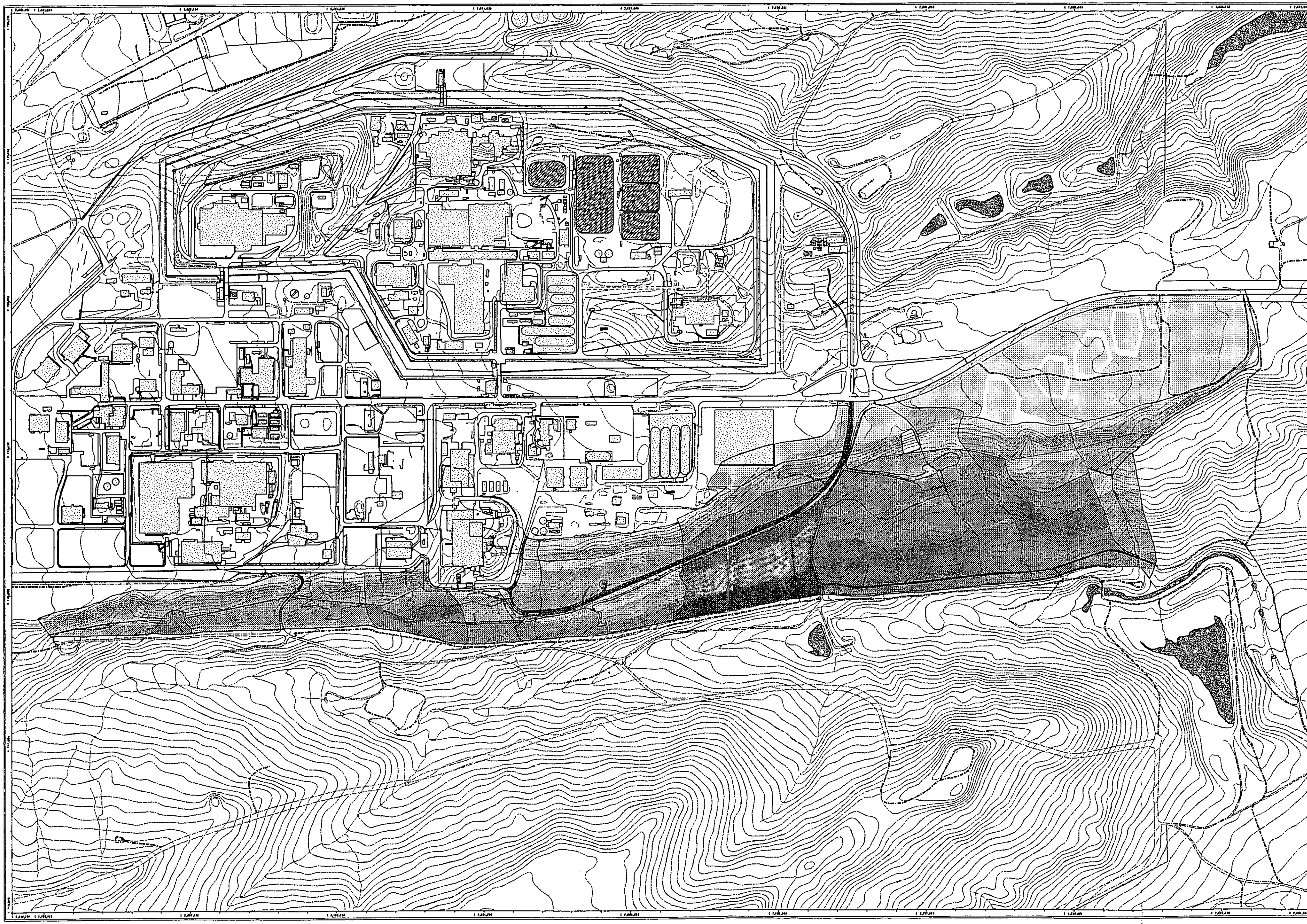


Figure 20

100-Year Event Erosion Map
South Interceptor Ditch (SID)

EXPLANATION

- > 0.400 Kg/m2 (0.737 Lbs/yd2) Deposition
- 0.200 Kg/m2 (0.369 Lbs/yd2) Deposition
- 0.020 Kg/m2 (0.037 Lbs/yd2) Deposition
- No Deposition or Detachment
- 0.010 Kg/m2 (0.018 Lbs/yd2) Detachment
- 0.025 Kg/m2 (0.046 Lbs/yd2) Detachment
- 0.050 Kg/m2 (0.092 Lbs/yd2) Detachment
- 0.100 Kg/m2 (0.184 Lbs/yd2) Detachment
- 0.150 Kg/m2 (0.276 Lbs/yd2) Detachment
- 0.200 Kg/m2 (0.369 Lbs/yd2) Detachment
- 0.250 Kg/m2 (0.461 Lbs/yd2) Detachment
- 0.300 Kg/m2 (0.553 Lbs/yd2) Detachment
- 0.350 Kg/m2 (0.645 Lbs/yd2) Detachment
- Road Detachment

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (5-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudsen (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~10 meter resolution. DEM post-processing performed by MK, Winter 1997.
Data Source:
Erosion data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 7880
1 inch represents approximately 657 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0266/sid_erosion_100yr.aml July 06, 2000

NT_Svr h:/projects/fy2k/2k-0266/sid_erosion_100yr.aml

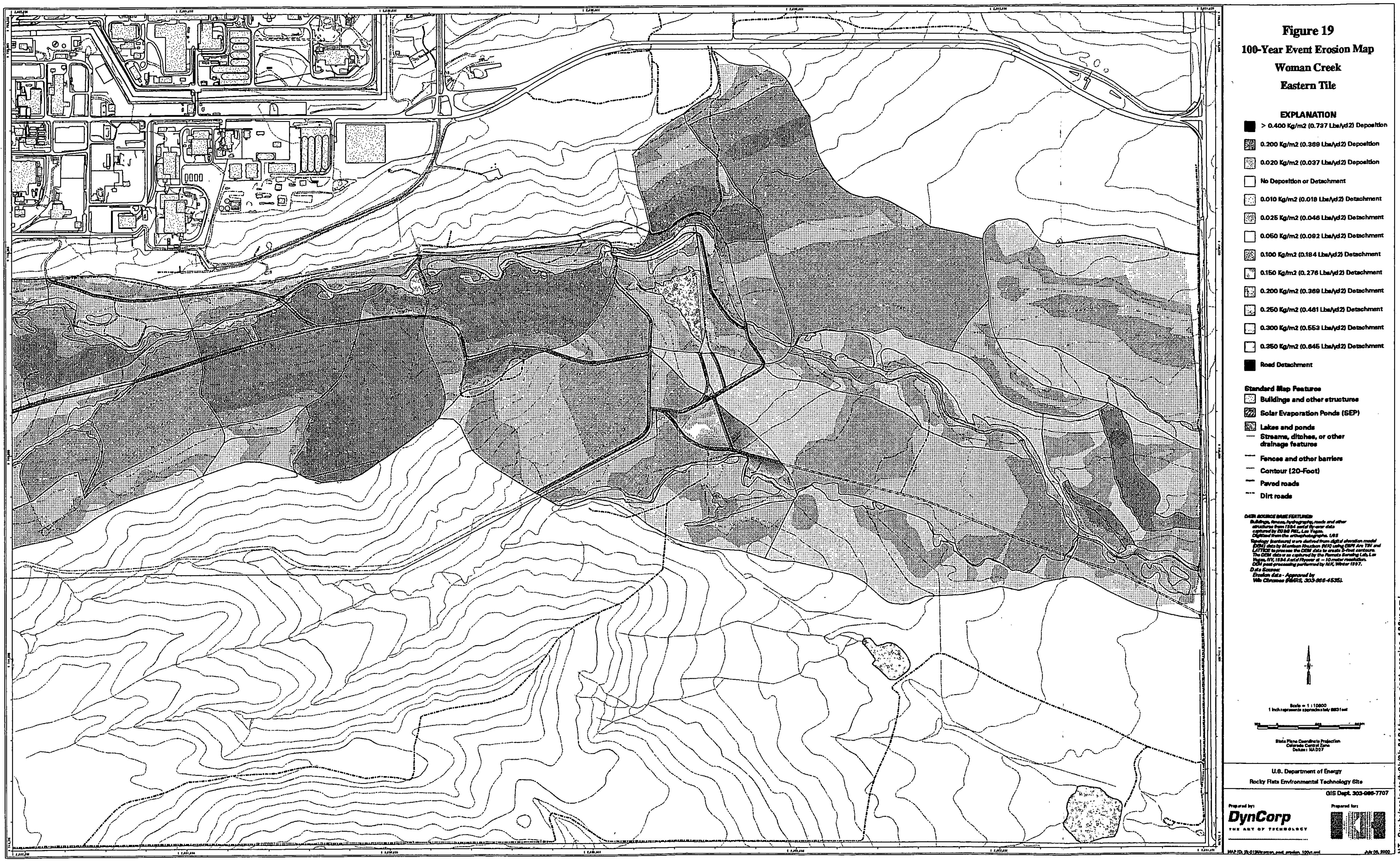


Figure 19
100-Year Event Erosion Map
Woman Creek
Eastern Tile

129

Figure 18
100-Year Event Erosion Map
Woman Creek
Western Tile

EXPLANATION

- > 0.400 Kg/m2 (0.737 Lbs/yd2) Deposition
- 0.200 Kg/m2 (0.369 Lbs/yd2) Deposition
- 0.020 Kg/m2 (0.037 Lbs/yd2) Deposition
- No Deposition or Detachment
- 0.010 Kg/m2 (0.018 Lbs/yd2) Detachment
- 0.025 Kg/m2 (0.046 Lbs/yd2) Detachment
- 0.050 Kg/m2 (0.092 Lbs/yd2) Detachment
- 0.100 Kg/m2 (0.184 Lbs/yd2) Detachment
- 0.150 Kg/m2 (0.276 Lbs/yd2) Detachment
- 0.200 Kg/m2 (0.369 Lbs/yd2) Detachment
- 0.250 Kg/m2 (0.461 Lbs/yd2) Detachment
- 0.300 Kg/m2 (0.553 Lbs/yd2) Detachment
- 0.350 Kg/m2 (0.645 Lbs/yd2) Detachment
- Road Detachment

Standard Map Features

- Buildings and other structures
- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (20-Foot)
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas.
Digitized from the orthophotographs. 1/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudsen (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours.
The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~10 meter resolution.
DEM post-processing performed by MK, Winter 1997.
Data Source:
Erosion data - Approved by
Win Chromec (RMRS, 303-966-4536).

Scale = 1 : 10800
1 inch represents approximately 833 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0124/woman_west_erosion_100yr.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0124/woman_west_erosion_100yr.aml

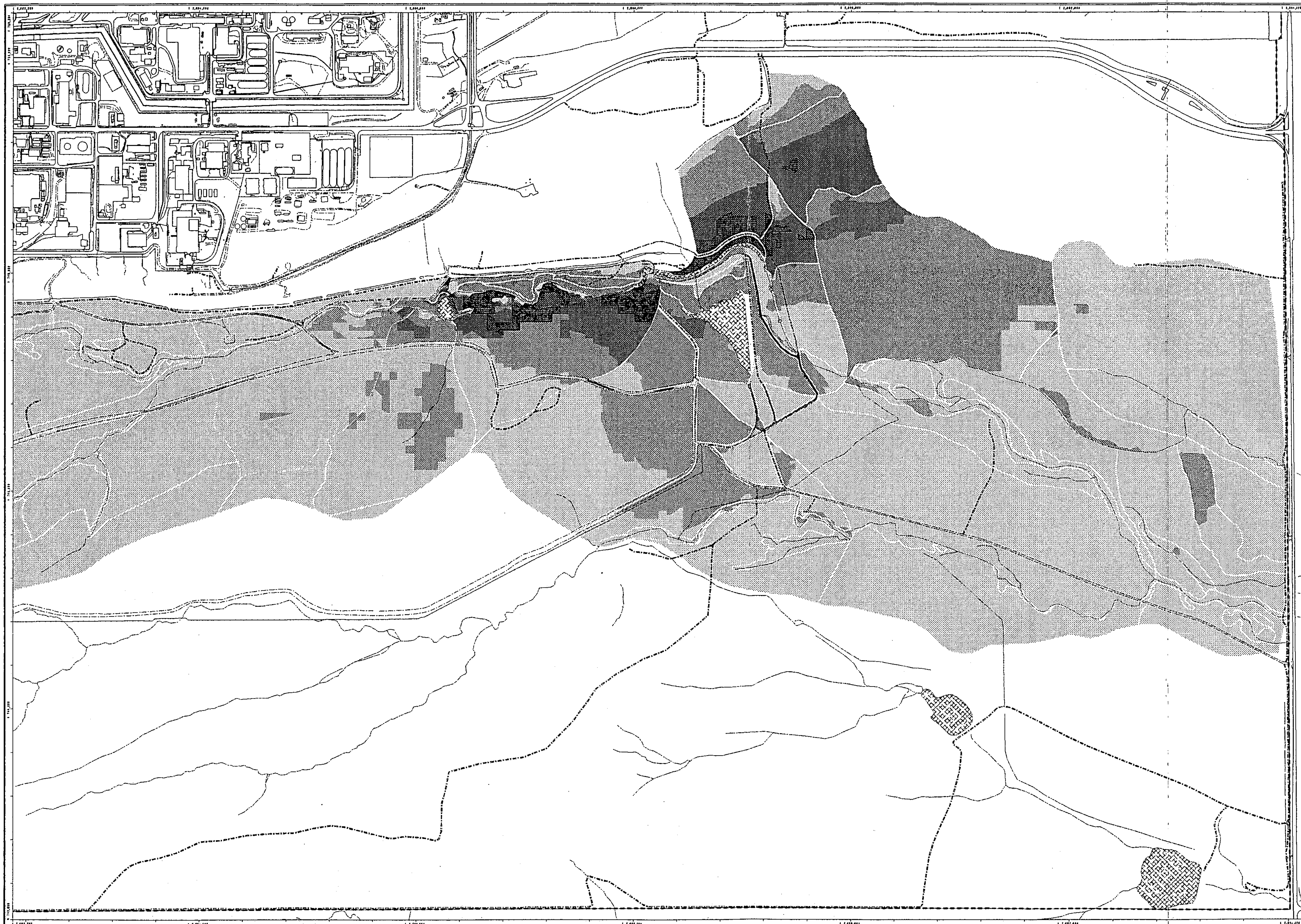


Figure 34

100-Year Average Am-241 Mobility Map

Woman Creek

Eastern Tile

EXPLANATION

- < = 10 pCi/m2 (0.929 pCi/ft2)
- < = 50 pCi/m2 (4.645 pCi/ft2)
- < = 100 pCi/m2 (9.290 pCi/ft2)
- < = 250 pCi/m2 (23.226 pCi/ft2)
- < = 500 pCi/m2 (46.452 pCi/ft2)
- < = 750 pCi/m2 (69.677 pCi/ft2)
- < = 1000 pCi/m2 (92.903 pCi/ft2)
- < = 2500 pCi/m2 (232.258 pCi/ft2)
- < = 5000 pCi/m2 (464.515 pCi/ft2)
- > 5000 pCi/m2 (464.515 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas.
Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 10730
1 inch represents approximately 894 feet

250 0 500 1000 Ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0065/woman_east_am_mob_m2_100avg.aml
July 05, 2000

NT_Svr h:/projects/fy2k/2k-0065/woman_east_am_mob_m2_100avg.aml

144

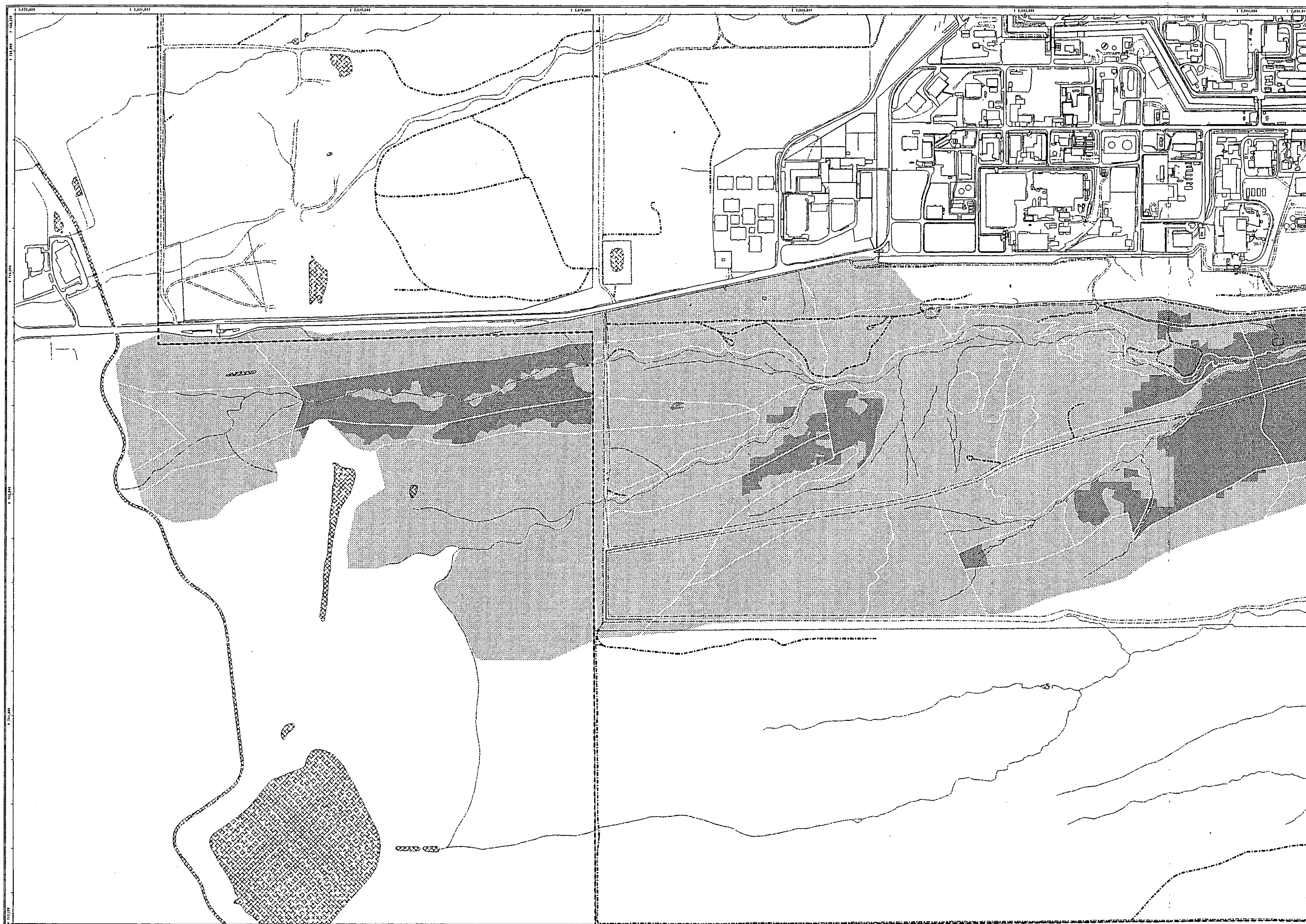


Figure 35

100-Year Event Pu-239 Mobility Map

Woman Creek

Western Tile

EXPLANATION

- <= 10 pCi/m2 (0.929 pCi/ft2)
- <= 100 pCi/m2 (9.290 pCi/ft2)
- <= 500 pCi/m2 (46.452 pCi/ft2)
- <= 1000 pCi/m2 (92.903 pCi/ft2)
- <= 2000 pCi/m2 (185.806 pCi/ft2)
- <= 3000 pCi/m2 (278.709 pCi/ft2)
- <= 4000 pCi/m2 (371.612 pCi/ft2)
- <= 5000 pCi/m2 (464.515 pCi/ft2)
- <= 10000 pCi/m2 (929.030 pCi/ft2)
- <= 25000 pCi/m2 (2322.576 pCi/ft2)
- > 25000 pCi/m2 (2322.576 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 10690
1 inch represents approximately 883 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0124/woman_west_pu_mob_m2_100yr.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0124/woman_west_pu_mob_m2_100yr.aml

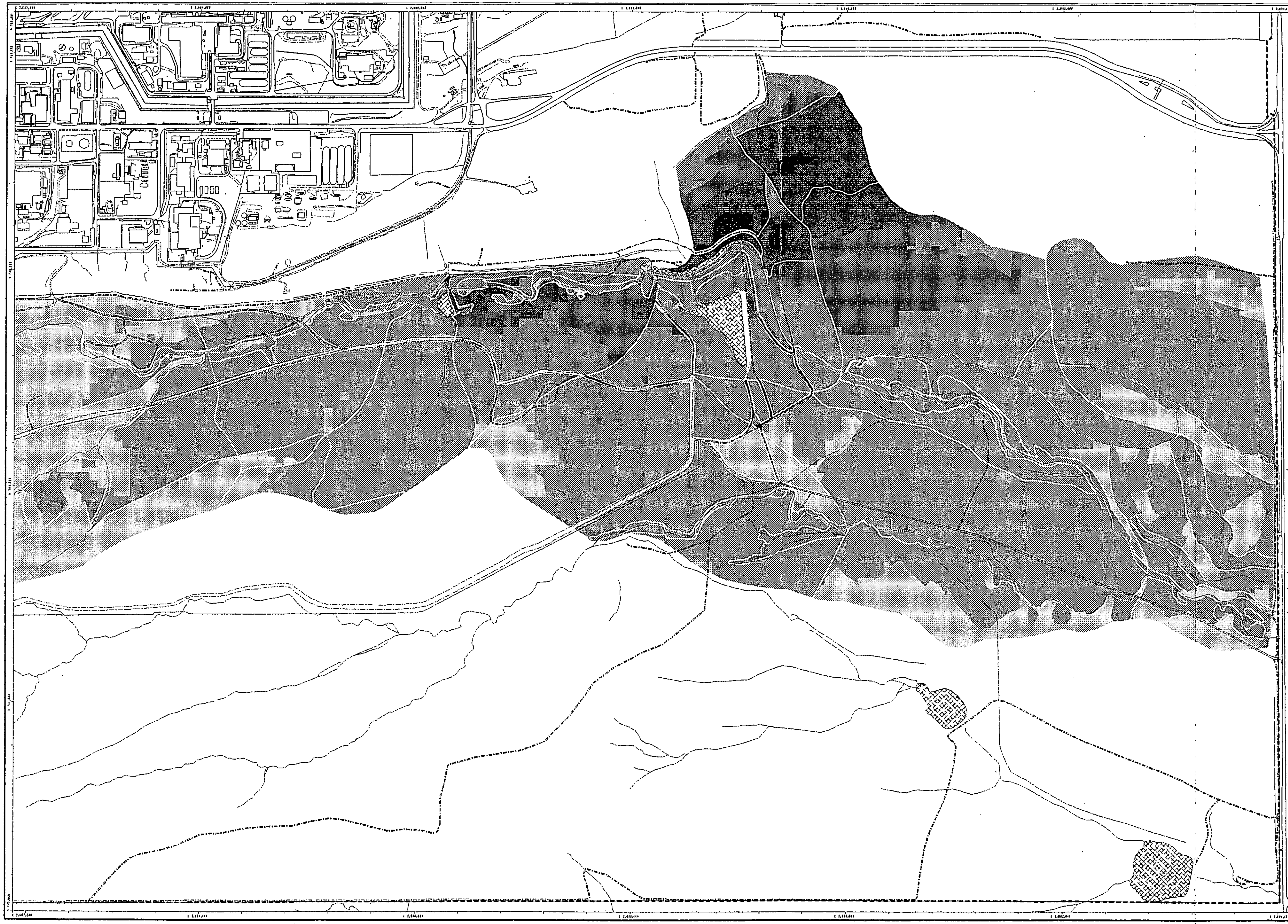


Figure 36

100-Year Event Pu-239 Mobility Map

Woman Creek Eastern Tile

EXPLANATION

- <= 10 pCi/m2 (0.929 pCi/ft2)
- <= 100 pCi/m2 (9.290 pCi/ft2)
- <= 500 pCi/m2 (46.452 pCi/ft2)
- <= 1000 pCi/m2 (92.903 pCi/ft2)
- <= 2000 pCi/m2 (185.806 pCi/ft2)
- <= 3000 pCi/m2 (278.709 pCi/ft2)
- <= 4000 pCi/m2 (371.612 pCi/ft2)
- <= 5000 pCi/m2 (464.515 pCi/ft2)
- <= 10000 pCi/m2 (929.030 pCi/ft2)
- <= 25000 pCi/m2 (2322.576 pCi/ft2)
- > 25000 pCi/m2 (2322.576 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas.
Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 10750
1 inch represents approximately 894 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0124/woman_east_pu_mob_m2_100yr.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0124/woman_east_pu_mob_m2_100yr.aml

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NT_Svr h:/projects/fy2k/2k-0124/woman_west_am_mob_m2_100yr.aml

147

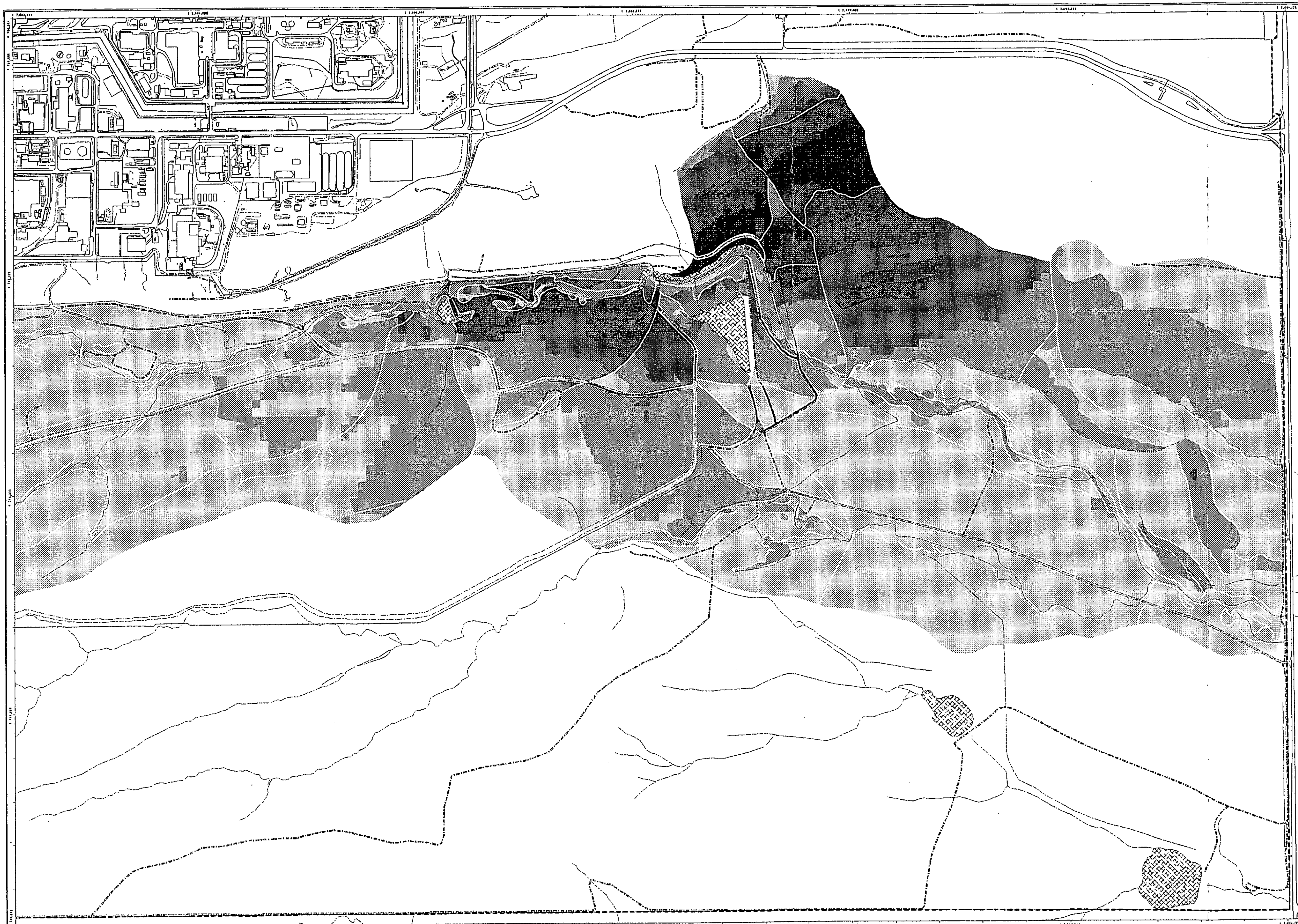

Figure 38

100-Year Event Am-241 Mobility Map

Woman Creek

Eastern Tile

EXPLANATION

- < = 10 pCi/m2 (0.929 pCi/ft2)
- < = 50 pCi/m2 (4.645 pCi/ft2)
- < = 100 pCi/m2 (9.290 pCi/ft2)
- < = 250 pCi/m2 (23.226 pCi/ft2)
- < = 500 pCi/m2 (46.452 pCi/ft2)
- < = 750 pCi/m2 (69.677 pCi/ft2)
- < = 1000 pCi/m2 (92.903 pCi/ft2)
- < = 2500 pCi/m2 (232.258 pCi/ft2)
- < = 5000 pCi/m2 (464.515 pCi/ft2)
- > 5000 pCi/m2 (464.515 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 10730
1 inch represents approximately 894 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0124/woman_east_am_mob_m2_100yr.aml July 06, 2000

NT_Svr h:/projects/fy2k/2k-0124/woman_east_am_mob_m2_100yr.aml

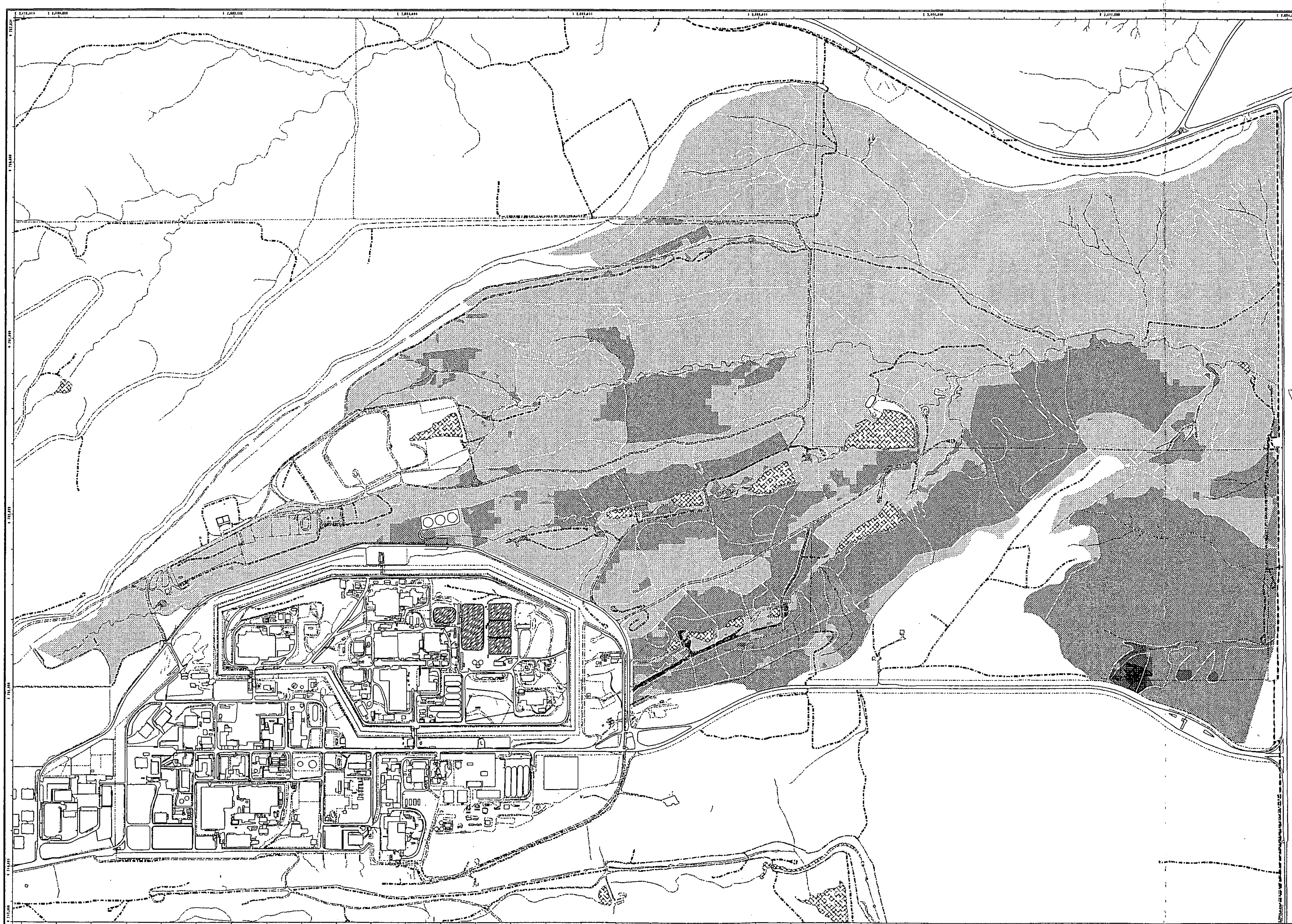

Figure 39

100-Year Average Pu-239 Mobility Map

Walnut Creek

EXPLANATION

- < = 10 pCi/m2 (0.929 pCi/ft2)
- < = 100 pCi/m2 (9.290 pCi/ft2)
- < = 500 pCi/m2 (46.452 pCi/ft2)
- < = 1000 pCi/m2 (92.903 pCi/ft2)
- < = 2000 pCi/m2 (185.806 pCi/ft2)
- < = 3000 pCi/m2 (278.709 pCi/ft2)
- < = 4000 pCi/m2 (371.612 pCi/ft2)
- < = 5000 pCi/m2 (464.515 pCi/ft2)
- < = 10000 pCi/m2 (929.030 pCi/ft2)
- < = 25000 pCi/m2 (2322.576 pCi/ft2)
- > 25000 pCi/m2 (2322.576 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 13250
1 inch represents approximately 1104 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0066/walnut_pu_mob_m2_100avg.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0066/walnut_pu_mob_m2_100avg.aml

Figure 40

100-Year Average Am-241 Mobility Map

Walnut Creek

EXPLANATION

- <= 10 pCi/m2 (0.929 pCi/ft2)
- <= 50 pCi/m2 (4.645 pCi/ft2)
- <= 100 pCi/m2 (9.290 pCi/ft2)
- <= 250 pCi/m2 (23.226 pCi/ft2)
- <= 500 pCi/m2 (46.452 pCi/ft2)
- <= 750 pCi/m2 (69.677 pCi/ft2)
- <= 1000 pCi/m2 (92.903 pCi/ft2)
- <= 2500 pCi/m2 (232.258 pCi/ft2)
- <= 5000 pCi/m2 (464.515 pCi/ft2)
- > 5000 pCi/m2 (464.515 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-866-4535).

Scale = 1 : 13250
1 inch represents approximately 1104 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: DynCorp THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0066/walnut_am_mob_m2_100avg.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0066/walnut_am_mob_m2_100avg.aml

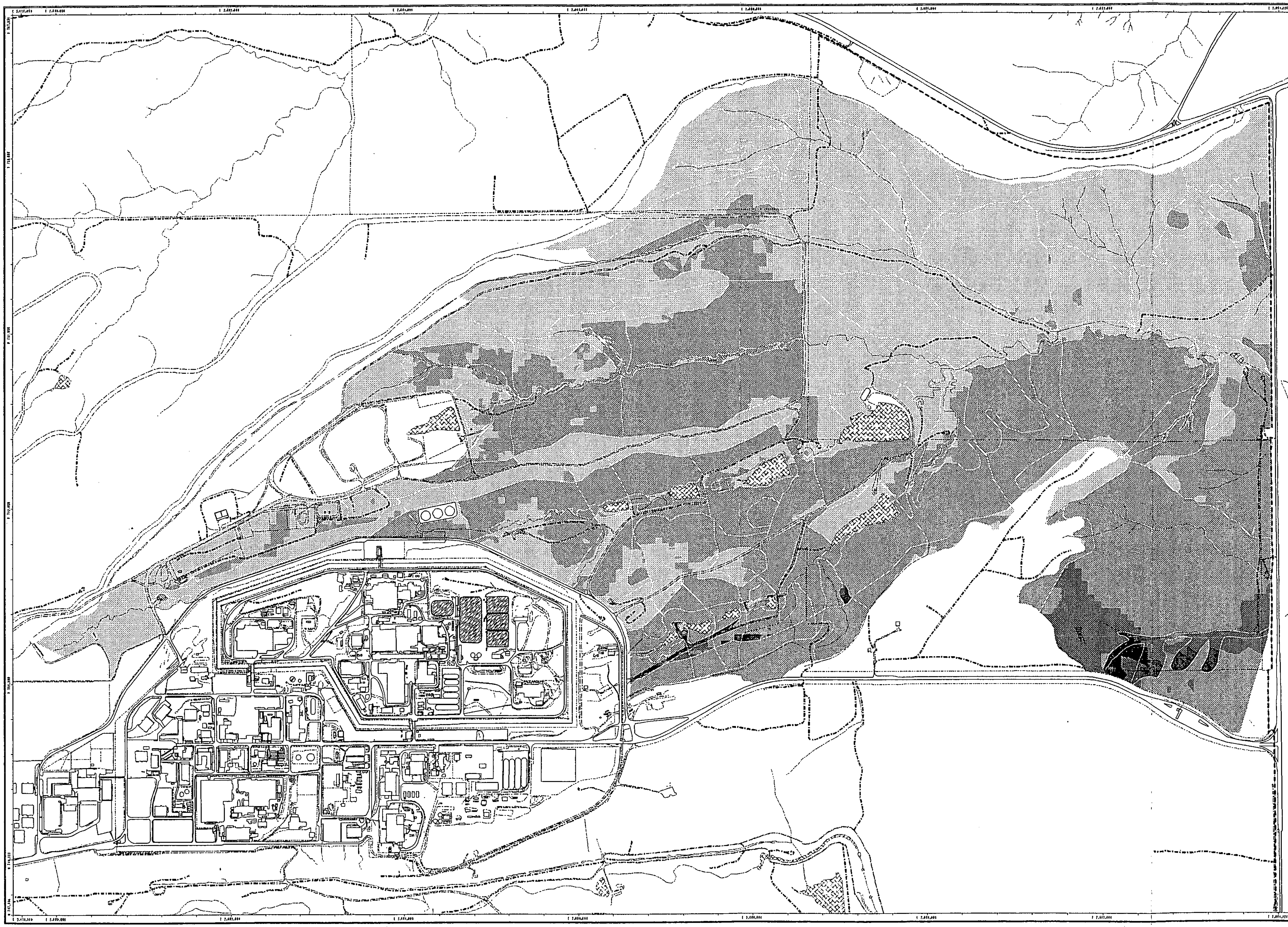

Figure 41

100-Year Event Pu-239 Mobility Map

Walnut Creek

EXPLANATION

<= 10 pCi/m2 (0.929 pCi/ft2)

<= 100 pCi/m2 (9.290 pCi/ft2)

<= 500 pCi/m2 (46.452 pCi/ft2)

<= 1000 pCi/m2 (92.903 pCi/ft2)

<= 2000 pCi/m2 (185.806 pCi/ft2)

<= 3000 pCi/m2 (278.709 pCi/ft2)

<= 4000 pCi/m2 (371.612 pCi/ft2)

<= 5000 pCi/m2 (464.515 pCi/ft2)

<= 10000 pCi/m2 (929.030 pCi/ft2)

<= 25000 pCi/m2 (2322.576 pCi/ft2)

> 25000 pCi/m2 (2322.576 pCi/ft2)

Standard Map Features

Solar Evaporation Ponds (SEP)

Lakes and ponds

Streams, ditches, or other drainage features

Fences and other barriers

Rocky Flats boundary

Paved roads

Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas.
Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 13250
1 inch represents approximately 1104 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: DynCorp THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0100/walnut_pu_mob_m2_100yr.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0139/walnut_pu_mob_m2_100yr.aml

151

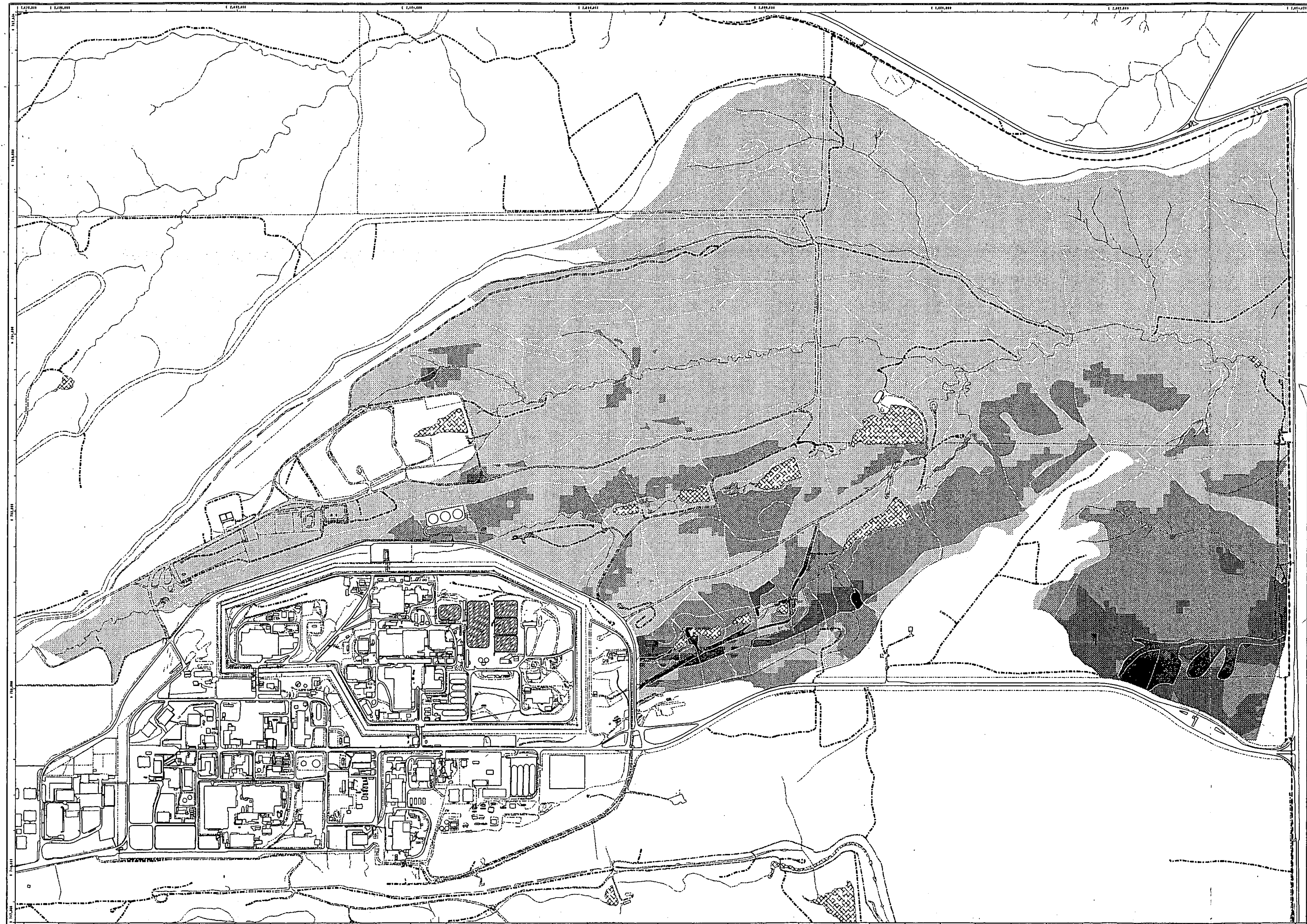

Figure 42
100-Year Event Am-241 Mobility Map
Walnut Creek

EXPLANATION

- <= 10 pCi/m2 (0.929 pCi/ft2)
- <= 50 pCi/m2 (4.645 pCi/ft2)
- <= 100 pCi/m2 (9.290 pCi/ft2)
- <= 250 pCi/m2 (23.226 pCi/ft2)
- <= 500 pCi/m2 (46.452 pCi/ft2)
- <= 750 pCi/m2 (69.677 pCi/ft2)
- <= 1000 pCi/m2 (92.903 pCi/ft2)
- <= 2500 pCi/m2 (232.258 pCi/ft2)
- <= 5000 pCi/m2 (464.515 pCi/ft2)
- > 5000 pCi/m2 (464.515 pCi/ft2)

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Mobility data - Approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 13250
1 inch represents approximately 1104 feet

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0133/walnut_am_mob_m2_100yr.aml
July 05, 2000

NT_Svr h:/projects/fy2k/2k-0133/walnut_am_mob_m2_100yr.aml

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Table A-3. Input for RFETS Rangeland Habitats - Initial Conditions Parameters For the WEPP Model

WEPP Model Plant File Parameter Description	WEPP Parameter Code	Erosion Sensitivity of Parameter[2]	Input Values For Rangeland Habitat Communities[1]															
			XTGP1	NEEDLE	MESIC	REGRASS	AGRASS	SMARSH	TMARSH	WETMEDW	LEAD	SHORTUP	RIPWOOD	WILLOW	GRAZE	IMPROAD	MEROAD	PAVEMENT	SIMULATOR
Initial frost depth (m), real-(frdp)	frdp	None	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Average rainfall during growing season (m), real-(pptg)	pptg	None	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256	0.256
Initial residue mass above the ground (kg/m2), real-(rmagt)	rmagt	Moderate	0.057	0.079	0.051	0.0506	0.0729	0.113	0.222	0.06	0.0506	0.05	0.048	0.06	0.0506	0	0.045	0	0.0729
Initial residue mass on the ground(kg/m2), real-(rmogt)	rmogt	Moderate	0.1115	0.1714	0.1036	0.1037	0.1037	0.226	0.444	0.1125	0.1036	0.09	0.18	0.1125	0.1036	0	0.0863	0	0.1137
Initial random roughness for rangeland (m), real-(rrough)	rrough	High	0.001	0.007	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.001	0.005	0.01	0.02	0.01	0.001	0.0046
Initial snow depth (m), real-(snodpy)	snodpy	None	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Initial depth of thaw (m), real-(thdp)	thdp	None	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Depth of secondary tillage layer (m), real -(tillay(1))	tillay(1)	None	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Depth of primary tillage layer (m), real-(tillay(2))	tillay(2)	None	0.2	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Interrill litter surface cover (0-1), real-(resi)	resi	High	0.3	0.3.0.66	0.49	0.6	0.554	0.623	0.355	0.503	0.785	0.51	0.51	0.82	0.49	0.1/0	0.332	0	0.53
Interrill rock surface cover (0-1), real-(roki)	roki	High	0.22	0.18/0.03	0.14	0.121	0.133	0.027	0.001	0.14	0.025	0.06	0.08	0.073	0.14	0.36/0/0.9	0.14/0.34	0.99	0.01
Interrill basal surface cover (0-1), real(basi)	basi	High	0.1	0.1/0.19	0.45	0.25	0.03	0.27	0.075	0.291	0.13	0.176	0.235	0.08	0.26	0	0.17	0	0.425
Interrill cryptogramic surface cover (0-1), real-(cryi)	cryi	High	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rill litter surface cover (0-1), real(resr)	resr	High	0.087	0.087/0.078	0.27	0.3	0.141	0.4	0.291	0.25	0.29	0.17	0.3	0.3	0.16	0.01	0.12	0	0.3325
Rill rock surface cover (0-1), real(rokr)	rokr	High	0.45	0.45/0.004	0.14	0.121	0.198	0.003	0.001	0.14	0.025	0.02	0.08	0.073	0.14	.36/0.45/0.9	0.140.34	0.99	0.05
Rill basal surface cover (0-1), real-(basr)	basr	High	0.035	0.035/0.023	0.35	0.25	0.035	0.06	0.061	0.12	0.05	0.059	0.12	0.05	0.08	0	0.28	0	0.25
Rill cryptogamic surface cover (0-1), real-(cryr)	cryr	High	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total foliar (canopy) cover (0-1), real (cancov)	cancov	High	0.7	0.7/0.89	0.74	0.76/0.66/0.78	0.74/0.76	0.82	0.55	0.91	0.3	0.75	0.22	0.28	0.74	0	0.55/0.35	0	0.785

[2] From WEPP Technical Documentation (Flanagan et al., 1995)

[1] Key to Rocky Flats Environmental Technology Site Habitat Communities	
Group Code	**Habitat Description**
XTGP	Xeric Tall Grass Prairie
NEEDLE	Xeric Needle-and-Threadgrass Prairie
MESIC	Mixed Mesic Grassland
REGRASS	Reclaimed Grassland
AGRASS	Annual Grass and Forb Community
SMARSH	Short Marsh
TMARSH	Tall Marsh
WETMEDW	Wet Meadow
LEAD	Leadplant Riparian Shrubland
SHORTUP	Short Upland Shrubland
RIPWOOD	Riparian Woodland
WILLOW	Riparian Willow Shrubland
GRAZED	Grazed Off-Site Areas
IMPROAD	Improved Gravel Road
MEROAD	Unimproved, Partially Vegetated Road
PAVEMENT	Paved Surfaces (e.g. Buildings, Roads, Parking Lots)

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Table A-4. Input Data for RFETS Rangeland Habitats – Plant Management Files for the WEPP Model

WEPP Model Plant File Parameter Description	WEPP Parameter Code	Erosion Sensitivity of Parameter[2]	Input Values For Rangeland Habitat Communities[1]																
			XTGP	NEEDLE	MESIC	REGRASS	AGRASS	SMARSH	TMARSH	WETMEDW	LEAD	SHORTUP	RIPWOOD	WILLOW	GRAZED	IMPROAD	MEROAD	PAVEMENT	SIMULATOR
Change in surface residue mass coefficient, real - (aca)	aca	Moderate	1	1	2	1	3	2	1	1	1	4.5	4.5	3.2	2	5	2	5	1.5
Coefficient for leaf area index, real-(aleaf)	aleaf	Moderate	1297	104	380	206	380	1078	1297	1078	300	201	500	350	380	4	380	4	380
Change in root mass coefficient, real-(ar)	ar	Moderate	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0.1	0	0.1	0.1	0.05	2	0.05	1	0.05
Parameter value for canopy height equation, real-(bbb)	bbb	Slight	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	2.1	4.8	2.9	4.8	1	4.8	1	4.8
Daily removal of surface residue by insects, real-(bugs)	bugs	Moderate	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0	0.0001	0	0.0001
Fraction of 1st peak of growing season, real-(cf1)	cf1	Moderate	0.88	0.88	0.9	0.81	0.9	0.9	100	0.8	0.8	88	0.88	0.88	0.9	1	0.9	1	0.9
Fraction of 2nd peak of growing season, real-(cf2)	cf2	Moderate	0.12	0.12	0.1	0.19	0.1	0.1	0	0.2	0.2	12	0.12	0.12	0.1	0	0.1	0	0.1
Carbon:Nitrogen ratio of residue and roots, real-(cn)	cn	Moderate	29	29	29	29	29	29	31	26	25	29	29	29	29	29	30	1	29
Standing biomass where canopy cover is 100%,(kg/m2)real-(cold)	cold	None	0.1577	0.176	0.132	0.182/0.132	0.182	0.132	0.82	0.132	0.132	0.13	2.5	0.9	0.132	0.132	0.132	1	0.182
Frost free period, (days)integer-(ffp)	ffp	None	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	132	0.132
Projected plant area coefficient for grasses, real-(gcoeff)	gcoeff	Slight	0.7	0.7	0.7	0.7	0.7	0.7	0.9	0.7	0.7	0.7	0.7	0.7	0.7	0.1	0.6	0.01	0.7
Average.canopy diameter for grasses, (m)real-(gdiam)	gdiam	Slight	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.01	0.1	0.01	0.1
Average height for grasses (m),real-(ghgt)	ghgt	Slight	0.35	0.35	0.33	0.33	0.47	0.33	0.47	0.33	0.33	0.35	0.35	0.35	0.33	0.01	0.3	0.01	0.28
Average number of grasses along a 100m belt transect, real-(gpop)	gpop	Moderate	3308	3308	4253	1487	1701	4096	421	4253	2172	2442	3229	315	2253	1	500	1	101
Minimum temperature to initiate growth,(degrees C) real-(gtemp)	gtemp	Moderate	5	5	2	5	2	2	5	5	5	5	5	5	2	5	2	10	2
Maximum herbaceous plant height (m), real-(hmax)	hmax	Slight	0.5	0.5	0.5	0.5	0.5	0.5	1.5	0.6	0.5	0.25	0.25	0.5	0.5	0.01	0.3	0.01	0.5
Maximum standing live biomass, (kg/m2)real-(plive)	plive	Moderate	0.125	0.158	0.125	0.12	0.14	0.125	0.5	0.12	0.4	1.85	2.65	0.125/1	0.125	0.01	0.11	0.01	0.125
Plant drought tolerance factor, real-(pltol)	pltol	Moderate	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0	0.2
Day of peak standing crop, 1st peak, (julian day) interger-(pscday)	pscday	Moderate	160	160	128	159	128	128	176	158	160	160	160	160	128	0	128	0	128
Minimum amount of live biomass, (kg/m2)real-(rgcmin)	rgcmin	Moderate	0.06	0.15	0.1	0.035	0.1	0.1	0.05	0.035	0.06	0.35	0.35	0.5	0.1	0	0.05	0.01	0.035
Root biomass in top 10cm, (kg/m2)real-(root10)	root10	High	1	2	1.02	1.02	1.02	1.02	1.8	0.46	1.02	1	2	2	1.02	0.01	0.8	0.01	1.02
Fraction of live and dead roots from maximum at start of year, real-(rootf)	rootf	High	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.01	0.5	0	0.66
Day on which peak occurs, 2nd growing season (julian day), interger-(scday2)	scday2	Moderate	270	270	250/278	270	278	278	247	287	287	267	267	247	278	0	278	0	278
Projected plant area coeffficient for shrubs, real-(scoeff)	scoeff	Slight	0.7	0.7	0.7	0	0	0.7	0	0.7	0.7	0.7	0.7	0.5	0.7	0	0	0	0
Average canopy diameter for shrubs (m), real-(sdiam)	sdiam	Slight	0.5	0.5	0.2	0	0	0.2	0	0.2	0.5	0.5	0.5	0.5	0.2	0	0	0	0
Average height of shrubs (m), real- (shgt)	shgt	Slight	0.47	0.47	0.2	0	0	0.2	0	0.2	1.25	0.47	1.2	1	0.2	0	0	0	0
Average number of shrubs along a 100m belt transect, real-(spop)	spop	Moderate	10	5	5	0	0	5	0	10	20	10	20	80	5	0	0	0	0
Projected plant area coefficient for trees, real-(tcoeff)	tcoeff	Slight	0	0	0	0	0	0	0	0	0.7	0	0.7	0.7/0.5	0	0	0	0	0
Average canopy diameter for trees(m), real-(tdiam)	tdiam	Slight	0	0	0	0	0	0	0	0	0.5	0	4	2	0	0	0	0	0
Minimum temperature to initiate senescence, (degrees C)real-(tempmn)	tempmn	Moderate	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
Average height for trees (m), real - (thgt)	thgt	Slight	0	0	0	0	0	0	0	0	2.5	0	18	4	0	0	0	0	0
Average number of trees along a 100m belt transect, real-(tpop)	tpop	Moderate	0	0	0	0	0	0	0	0	9	0	30	13	0	0	0	0	0
Fraction of initial standing woody biomass (%), real-(wood)	wood	Moderate	0	0	0	0	0	0	0	0	0	0	0	100/0	0	0	0	0	0

[2] From WEPP Technical Documentation (Flanagan et al., 1995)

[1] Key to Rocky Flats Environmental Technology Site Habitat Communities	
Group Code	Habitat Description
XTGP	Xeric Tall Grass Prairie
NEEDLE	Xeric Needle-and-Threadgrass Prairie
MESIC	Mixed Mesic Grassland
REGRASS	Reclaimed Grassland
AGRASS	Annual Grass and Forb Community
SMARSH	Short Marsh
TMARSH	Tall Marsh
WETMEDW	Wet Meadow
LEAD	Leadplant Riparian Shrubland
SHORTUP	Short Upland Shrubland
RIPWOOD	Riparian Woodland
WILLOW	Riparian Willow Shrubland
GRAZED	Grazed Off-Site Areas
IMPROAD	Improved Gravel Road
MEROAD	Unimproved, Partially Vegetated Road
PAVEMENT	Paved Surfaces (e.g. Buildings, Roads, Parking Lots)

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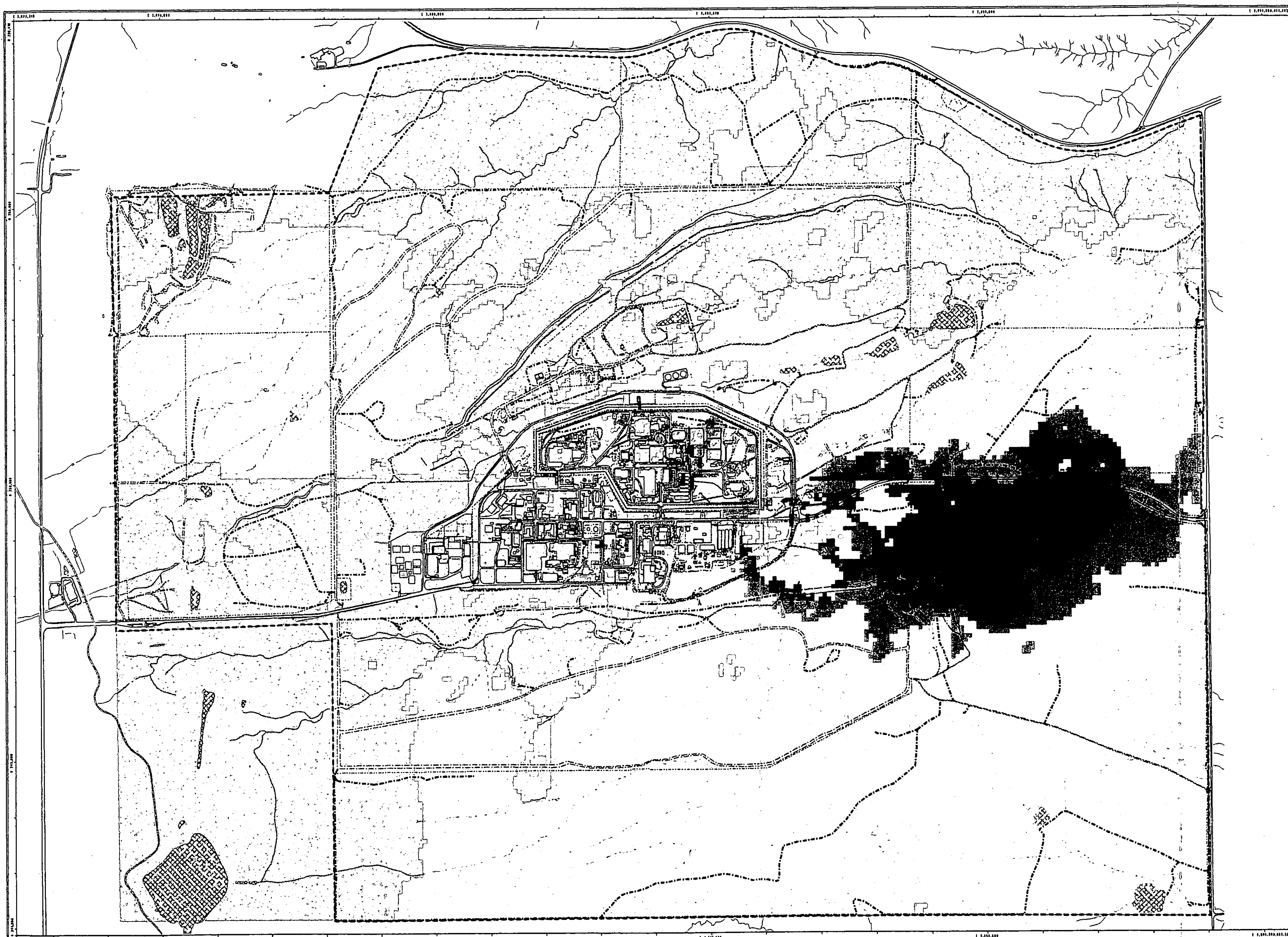

Figure B-11

Pu-239 Isoplot (pCi/g) (1999 Kriging Analysis)

EXPLANATION

- < = 0.1
- > 0.1 and < = 1.0
- > 1.0 and < = 5.0
- > 5.0 and < = 10.0
- > 10.0 and < = 25.0
- > 25.0 and < = 100.0
- > 100.0 and < = 252.0
- > 252.0 and < = 1429.0
- > 1429.0 and < = 10000.0
- > 10000.0

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:

Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95

Data Source:
PU-239 Kriging data approved by Win Chromec (RMRS, 303-966-4535).

Scale = 1 : 21330
1 inch represents approximately 1778 feet

500 0 1000 2000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0048/pu_grid.aml

July 06, 2000

NT_Svr h:/projects/fy2k/2k-0048/pu_grid.aml

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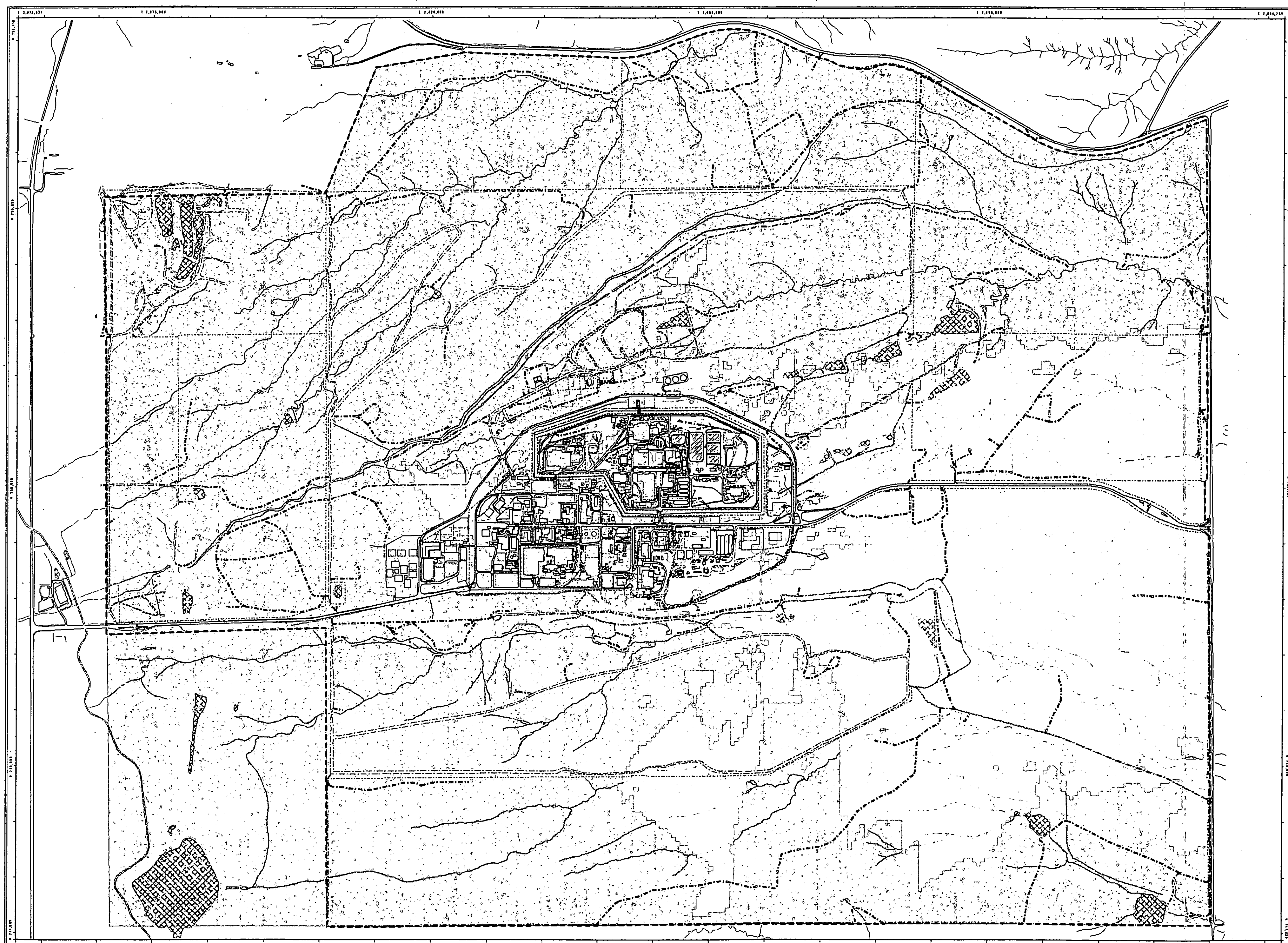


Figure B-12

Am-241 Isoplot (pCi/g) (1999 Kriging Analysis)

EXPLANATION

- < = 0.1
- > 0.1 and < = 1.0
- > 1.0 and < = 5.0
- > 5.0 and < = 10.0
- > 10.0 and < = 38.0
- > 38.0 and < = 215.0
- > 215.0 and < = 500.0
- > 500.0

Standard Map Features

- Solar Evaporation Ponds (SEP)
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source: AM-241 Kriging data approved by Win Chromec (RMRS, 303-966-4535).

N

Scale = 1 : 21330
1 inch represents approximately 1778 feet

500 0 1000 2000 ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 2k-0048/am_grid.aml

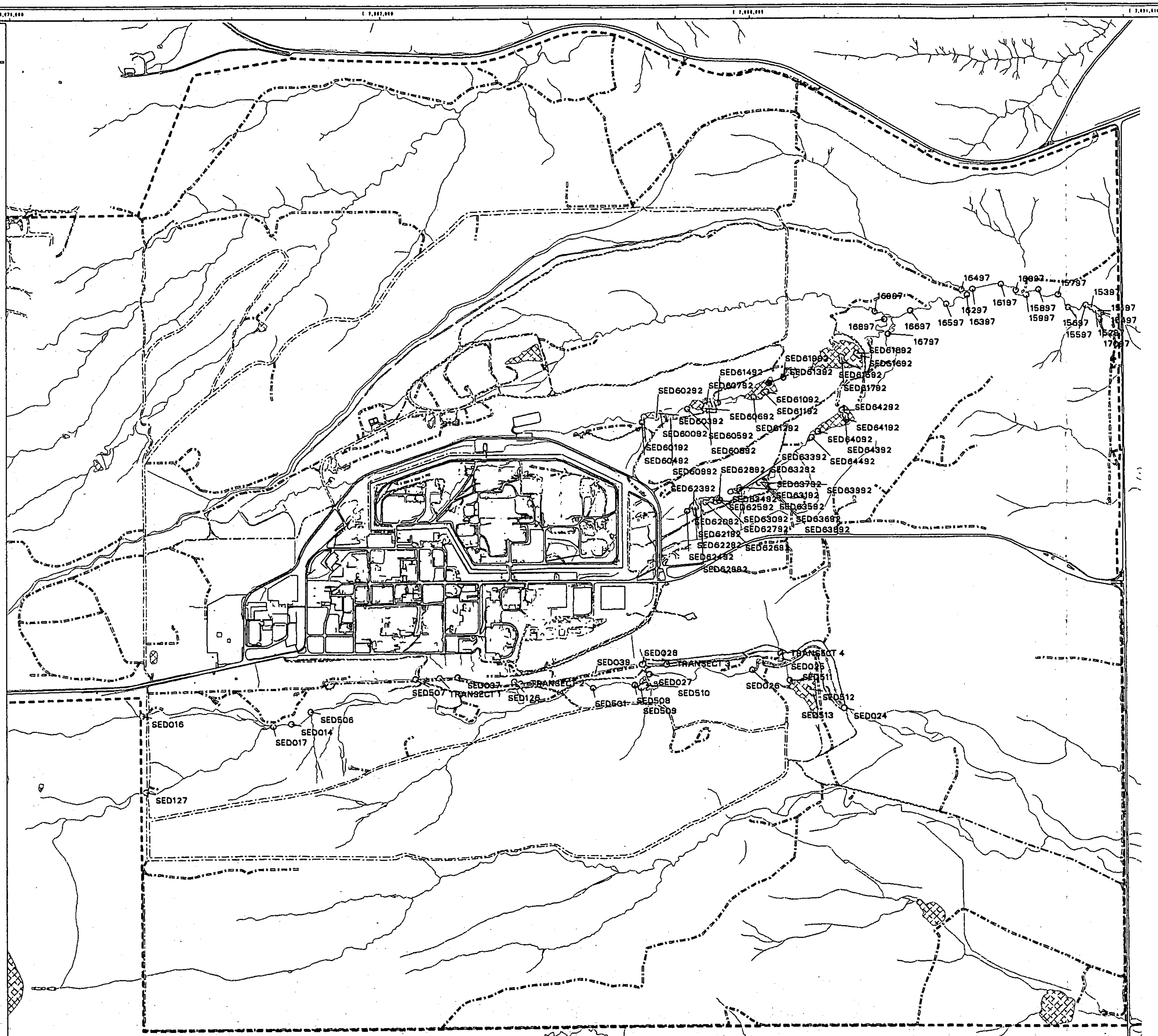
July 06, 2000

NT_Svr h:/projects/fy2k/2k-0048/am_grid.aml

PU-239 Sediment Sample Locations

Figure C-5

Location	Mean (pCi/g)	Std. Dev.	N
15197	0.052	----	1
15297	0.015	----	1
15397	0.044	----	1
15497	0.025	----	1
15597	0.065	----	1
15697	0.022	----	1
15797	0.084	----	1
15897	0.041	----	1
15997	0.056	----	1
16097	0.040	----	1
16197	0.077	----	1
16297	0.025	----	1
16397	0.143	----	1
16497	0.036	----	1
16597	0.035	----	1
16697	0.100	----	1
16797	2.320	----	1
16897	0.164	----	1
16997	-0.014	----	1
SED014	0.020	----	2
SED016	0.009	0.005	11
SED017	0.016	0.012	6
SED024	0.568	0.408	10
SED025	1.236	1.146	8
SED026	0.465	0.345	8
SED027	0.170	0.169	13
SED028	0.126	0.066	6
SED037	0.188	----	2
SED039	5.759	9.787	3
SED126	0.032	0.028	4
SED127	0.014	0.010	6
SED501	0.039	----	1
SED506	0.004	----	1
SED507	0.880	----	1
SED508	0.520	----	2
SED509	0.950	----	2
SED510	0.585	----	2
SED511	1.500	----	1
SED512	2.100	----	1
SED513	2.400	----	1
SED60092	13.898	18.696	3
SED60192	7.032	8.213	3
SED60292	13.508	19.653	3
SED60392	10.163	13.429	3
SED60492	4.909	4.652	3
SED60592	4.100	0.124	3
SED60692	4.761	3.661	3
SED60792	4.636	1.074	3
SED60892	2.828	0.250	3
SED60992	7.842	4.230	3
SED61092	2.053	----	1
SED61192	0.914	----	1
SED61292	1.304	----	1
SED61392	0.619	----	1
SED61492	1.182	----	1
SED61592	0.040	----	1
SED61692	0.178	----	1
SED61792	0.086	----	1
SED61892	0.286	----	1
SED61992	0.185	----	1
SED62092	656.083	----	2
SED62192	65.257	39.044	3
SED62292	347.856	----	2
SED62392	100.848	101.779	3
SED62492	156.520	58.171	3
SED62592	867.448	958.124	3
SED62692	330.300	300.736	3
SED62792	429.942	470.060	3
SED62892	160.555	107.182	3
SED62992	89.743	66.701	3
SED63092	11.890	----	1
SED63192	7.568	----	1
SED63292	60.680	----	1
SED63392	113.370	----	1
SED63492	21.970	----	1
SED63592	9.765	----	1
SED63692	0.833	----	1
SED63792	5.458	----	1
SED63892	12.495	----	1
SED63992	0.801	----	1
SED64092	0.241	----	1
SED64192	0.125	----	1
SED64292	0.208	----	1
SED64392	0.436	----	1
SED64492	0.182	----	1
SED68192	0.677	----	1
SED68492	0.629	----	1
SED68592	0.018	----	1
SED68692	0.119	----	1
SED68792	0.069	----	1
SED68892	0.159	----	1
SED69292	0.006	----	1
SED69392	0.169	----	1
SED69492	0.013	----	1
SED69692	0.065	----	1
SED69792	-0.008	----	1
SED69892	0.340	----	1
SED69992	0.068	----	1
SED70092	1.850	----	1
TRANSECT 1	0.072	----	1
TRANSECT 2	0.084	----	1
TRANSECT 3	0.882	----	1
TRANSECT 4	0.386	----	1



EXPLANATION

(Units = pCi/g)

- o < 0.1
- o > = 0.1 and < 0.5
- o > = 0.5 and < 1.0
- o > = 1.0 and < 5.0
- o > = 5.0 and < 10.0
- o > = 10.0 and < 100.0
- o > = 100.0 and < 1000.0
- o > = 1000.0

Standard Map Features

- Lakes and ponds
- Streams, ditches, or other drainage features
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Sediment data - Approved by Win Chromec (RMRS, 303-966-4535).

N

Scale = 1 : 21330
1 inch represents approximately 1778 feet

500 0 1000 2000 ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:
KAISER-HILL
COMPANY

MAP ID: 2k-0308/sed_pu239.aml

July 31, 2000

NT_Svr w:/projects/fy2k/2k-0308/sed_pu239.aml

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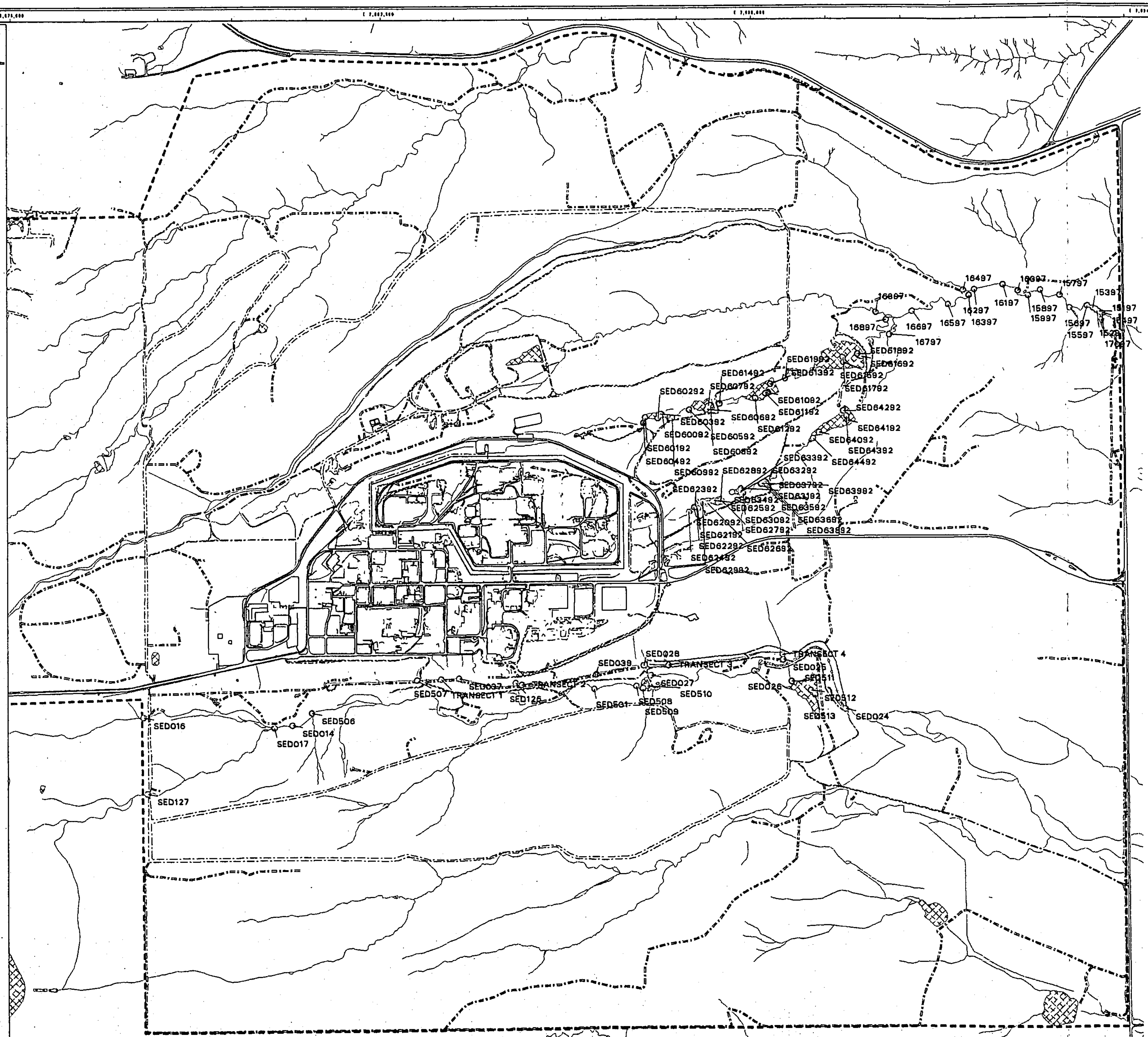
Location	Mean (pCi/g)	Std. Dev.	N
15197	0.081	----	1
15297	0.057	----	1
15397	0.089	----	1
15497	0.017	----	1
15597	0.057	----	1
15697	0.058	----	1
15797	0.047	----	1
15897	0.051	----	1
15997	0.059	----	1
16097	0.109	----	1
16197	0.133	----	1
16297	0.043	----	1
16397	0.312	----	1
16497	-0.014	----	1
16597	0.069	----	1
16697	0.080	----	1
16797	0.049	----	1
16897	0.086	----	1
16997	0.062	----	1
SED014	0.000	----	2
SED016	0.007	0.009	11
SED017	0.008	0.014	6
SED024	0.088	0.065	9
SED025	0.201	0.155	6
SED026	0.056	0.052	6
SED027	0.028	0.021	11
SED028	0.029	0.011	5
SED037	0.024	0.009	2
SED039	0.154	0.214	3
SED126	0.015	0.013	3
SED127	0.006	0.002	5
SED501	0.008	----	1
SED506	0.004	----	1
SED507	0.220	----	1
SED508	0.084	----	2
SED509	0.153	----	2
SED510	0.077	----	2
SED511	0.320	----	1
SED512	0.420	----	1
SED513	0.340	----	1
SED60092	4.667	6.567	3
SED60192	2.898	3.986	3
SED60292	4.956	7.165	3
SED60392	4.392	6.139	3
SED60492	0.672	0.009	3
SED60592	1.110	0.065	3
SED60692	1.784	0.867	3
SED60792	1.450	0.327	3
SED60892	0.804	0.149	3
SED60992	2.101	0.886	3
SED61092	0.666	----	1
SED61192	0.333	----	1
SED61292	0.422	----	1
SED61392	0.246	----	1
SED61492	0.397	----	1
SED61592	0.013	----	1
SED61692	0.093	----	1
SED61792	0.043	----	1
SED61892	0.136	----	1
SED61992	0.062	----	1
SED62092	220.677	----	2
SED62192	19.117	17.701	3
SED62292	98.581	----	2
SED62392	71.802	106.260	3
SED62492	32.511	26.605	3
SED62592	50.449	71.104	3
SED62692	32.669	40.150	3
SED62792	25.902	36.432	3
SED62892	28.790	28.721	3
SED62992	11.093	13.487	3
SED63092	3.426	----	1
SED63192	2.746	----	1
SED63292	21.841	----	1
SED63392	37.505	----	1
SED63492	6.895	----	1
SED63592	2.817	----	1
SED63692	0.458	----	1
SED63792	1.574	----	1
SED63892	3.968	----	1
SED63992	0.508	----	1
SED64092	0.077	----	1
SED64192	0.063	----	1
SED64292	0.123	----	1
SED64392	0.305	----	1
SED64492	0.079	----	1
SED68192	0.270	----	1
SED68492	0.218	----	1
SED68592	0.037	----	1
SED68692	0.059	----	1
SED68792	0.014	----	1
SED68892	0.070	----	1
SED69292	0.004	----	1
SED69392	0.050	----	1
SED69492	0.010	----	1
SED69692	0.033	----	1
SED69792	0.033	----	1
SED69892	0.312	----	1
SED69992	0.018	----	1
SED70092	0.746	----	1
TRANSECT 1	0.084	----	1
TRANSECT 2	0.100	----	1
TRANSECT 3	0.284	----	1
TRANSECT 4	0.083	----	1



AM-241 Sediment Sample Locations

Figure C-6

EXPLANATION

(Units = pCi/g)

- o < 0.1
- o >= 0.1 and < 0.5
- o >= 0.5 and < 1.0
- o >= 1.0 and < 5.0
- o >= 5.0 and < 10.0
- o >= 10.0 and < 100.0
- o >= 100.0 and < 1000.0
- o >= 1000.0

Standard Map Features

- Lakes and ponds
- Streams, ditches, or other drainage features
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/95
Data Source:
Sediment data - Approved by Win Chromec (RMRS, 303-966-4535).

N

Scale = 1 : 21330
1 inch represents approximately 1778 feet

500 0 1000 2000 Ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by: **DynCorp** THE ART OF TECHNOLOGY

Prepared for: KAISER-HILL COMPANY

MAP ID: 2k-0308/sed_am241.aml

July 31, 2000

NT_Svr w:/projects/fy2k/2k-0308/sed_am241.aml

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STREAM ID WOMAN TEAM MEMBERS CC-JR DIST TO PREVIOUS SECTION ___ FEET SHEET 1 OF 1
CROSSECTION ID W-7 WATERSHED ID ___ BEARING TO NEAREST VISABLE OBJECT 330'
APPROX. d_{50} = ___ INCHES CIRCLE ONE: AGGREGATED/DEDGRADATED/ARMORED/OTHER DESCRIPTION OF VISABLE OBJECT USED AIR TOWER

Example Field Data Sheet for Measurement of Channel Cross Section Geometry and Evaluation of Channel Roughness and Bed Sediment Gradation.

Cross Section of Woman Creek Channel in Segment 3

FIELD RECORD

ELEVATION/DISTANCE																								
Distance	0	0.5	1	2	3	4	5.5	7.0	9.0	12.0	14.0	16	17	19	21	22	23	24	26	28	30	32	34	36	44
Elevation	0	0.3	0.8	1.5	2.0	2.6	3.1	3.1	3.1	3.1	3.1	3.1	3.4	3.8	3.6	3.3	2.2	2.3	2.1	1.8	1.8	1.4	1.2	1.1	0

GRAPHIC SECTION

NOTES:

- [0 - 28 Willows]
- SANDY, SMALL COBBLE BOTTOM w/ LEAF LITTER
- SOME 10" STONES
- 50' UPSTREAM OF CONFLUENCE w/ SMART DITCH

SCALE: 1" = 1' V
1" = 5' H

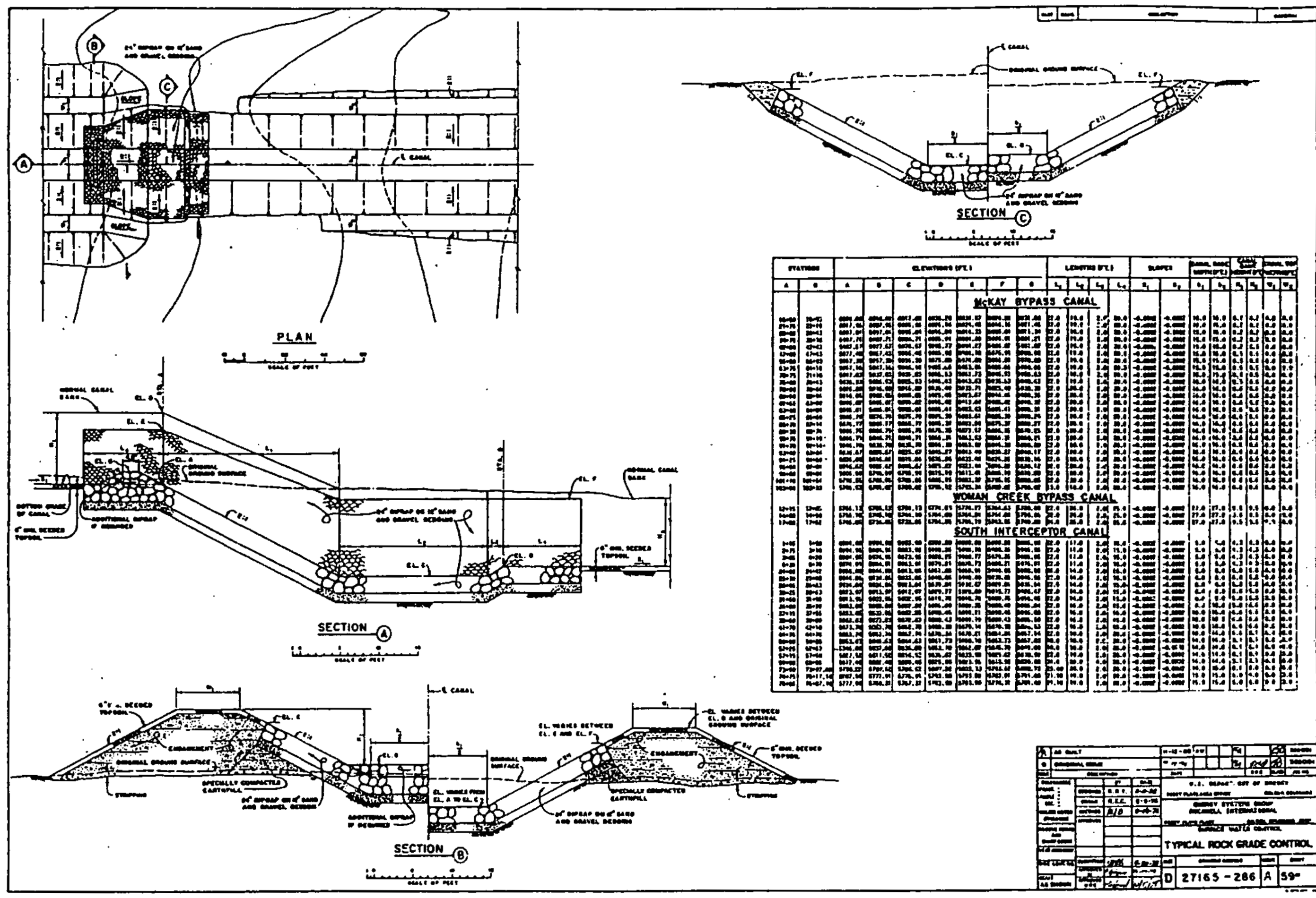
CROSS SECTION SKETCH TO INCLUDE: LOCATION AND DESCRIPTION OF CHANNEL GEOMETRY, SIZE AND LOCATION OF VEGETATIVE COMPONENTS AND NON-VEGETATIVE COMPONENTS. ALL SECTION DATA OBTAINED LEFT TO RIGHT LOOKING UPSTREAM.

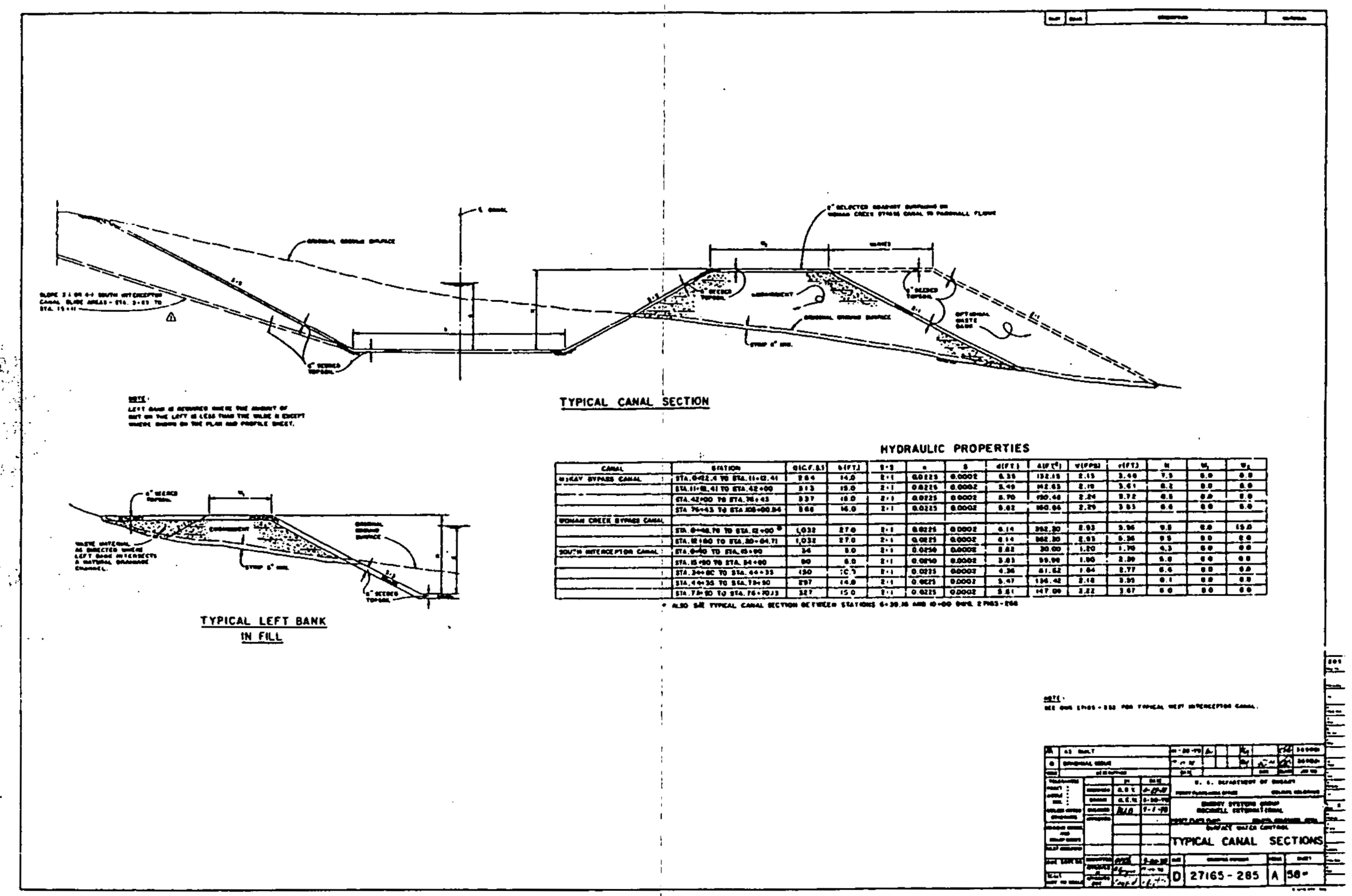
OFFICE USE
X-SECTION ID: ___ INFLOW HILLSLOPES RIGHT: ___ LEFT: ___
MANNINGS n LEFT: ___ DIST TO DS X-SEC: ___ BED DISTTRUBUTION: ___
MAIN: ___ RIGHT: ___ CHANNEL SLOPE: ___

WRIGHT WATER ENGINEERS, INC.
2490 W. 26TH AVE. SUITE 100A
DENVER, CO 80211 (303)480-1700

SURVEY ___
JOB NO. ___
SCALE 1"=5'

ROCKY FLATS SEDIMENT TRANSPORT MODEL
CHANNEL CROSS SECTION SURVEY





DESIGN DRAWINGS FOR ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE CANALS – showing specifications for 6 inches of seeded topsoil in the canals / ditches.

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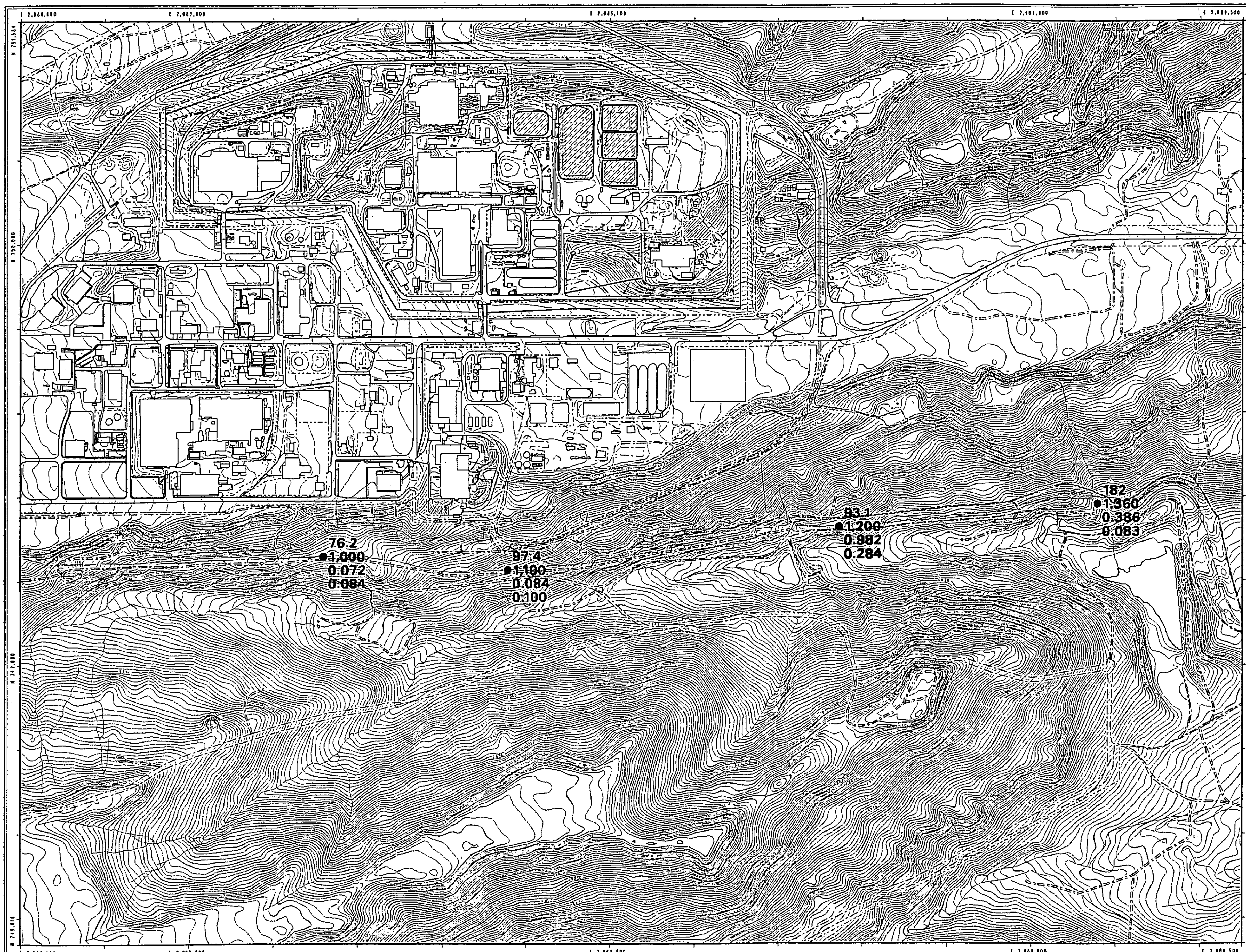

Appendix C
1999 South Interceptor Ditch Transects

EXPLANATION

● Cored Sediment Depth (mm)
Bulk Density (Kg/m3)
Pu (pCi/g)
Am (pCi/g)

Standard Map Features

Buildings and other structures

Solar Evaporation Ponds (SEP)

Lakes and ponds

Streams, ditches, or other drainage features

Fences and other barriers

Contour (2-Foot)

Paved roads

Dirt roads

DATA SOURCE BASE FEATURES:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 8/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudsen (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 2-foot contours. The DEM data was captured by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. DEM post-processing performed by MK, Winter 1997.
Data Source:
Transect data - Approved by Win Chromec (RMRS, 303-966-4535).

N

Scale = 1 : 8470
1 inch represents approximately 706 feet

250 0 500 1000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

GIS Dept. 303-966-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:

MAP ID: 99-0402

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